THE UNIVERSITY OF ALBERTA

SOME ECOLOGICAL EFFECTS OF THERMAL POLLUTION ON LAKE WABAMUN, ALBERTA, WITH SPECIAL REFERENCE TO THE ROTIFERA

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Some Ecological Effects of Thermal Pollution on Lake Wabamun, Alberta, with Special Reference to the Rotifera," submitted by John Patrick Kieran Horkan in partial fulfilment of the requirements for the degree of Master of Science.

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ABSTRACT

An ecological study was carried out on some of the chemical, physical and biological effects of a heated effluent from a thermal power plant on the north-east end of Lake Wabamun, from June 1968 to September 1970. Lake Wabamun is a shallow, silt bottom, hardwater eutrophic lake.

Thirteen stations were sampled. Seven of these were in the vicinity of the heated water from the outlet canal and experienced temperature increases of varying degrees depending upon their distance from the canal, prevailing winds and currents. Four stations were located near the inlet canal. The control station was established near the south shore of the lake and the remaining station was located near the west end of the lake. Maximum normal lake temperature was 20.4 C. and a maximum of 29.0 C. was recorded in the heated area (at station 2). A maximum temperature of 31.8 C. was recorded in the outlet canal.

On calm days the heated effluent floated as a plume on top of the cooler, denser lake water and this prevented the formation of ice during winter over about 5% of the lake in this region. Oxygen concentrations in the open water were generally higher than in water under the ice. Light intensity was also greater in open water than under a snow-ice cover where only 5.7% of the incident light penetrated the water on April 9, 1969. *Ceratium hirundinella* was found to show least preference for the warmest water but was found in greatest numbers at slightly elevated temperatures with an optimum at 21.9 C.

In general, rotifers were the most abundant zooplankters in the lake and 47 species were identified. The nine most common species were analysed in greatest detail to determine whether the heated water had any effect on the adults and eggs. *Kellicottia longispina* and *Keratella hiemalis* were the only two species that produced eggs and survived as adults over the 0 - 29 C. temperature range. *Asplanchna priodonta,* a carnivore producing live young, survived over the same temperature range. Adults of *Keratella cochlearis* survive the 0 - 29 C. temperature range but eggs were produced only between temperatures of 9.8 - 26.6 C. Eggs were rarely seen in *Polyarthra vulgaris* but adults were found in the 0 - 26.6 C. range. Adults of *Keratella earlinae* occurred at temperatures from 0 - 26.5 C. but egg production was limited to a narrow range from 16.5 - 26.5 C. The colonial species *Conochilus unicornis* occurred during the summer at temperatures from 9.8 - 25.6 C. *Notholca acuminata* and *Filinia longiseta* survived temperatures from 0 - 22.4 C., although eggs of the latter species occurred only from 12.0 - 22.4 C. All these species tolerated temperatures up to 2.0 C. higher than the maximum normal lake temperature of 20.4 C. It was concluded that temperatures in excess of 22.4 C. are detrimental to the rotifers in Lake Wabamun. The heated north-east end of the lake is regarded as being thermally polluted at temperatures above 22.4 C.

Populations of *Kellicottia longispina, Filinia longiseta* and *Keratella cochlearis* show an increased rate of population change with increased temperature. Populations of *Keratella hiemalis* have a decreased rate of change with increased temperature.

Data examined for six less common species of rotifers suggests that there is greater species diversity in the heated area.

ACKNOWLEDGEMENTS

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INTRODUCTION

As human populations continue to multiply, the need for recreational areas of a relatively unspoilt nature increases from year to year. Unfortunately, the ever-rising numbers of people continually increase the demands for waters not only for fishing and boating but also for a source of electricity to provide their cities and towns with light and power, as well as places to dump their industrial and domestic wastes. In Alberta, Lake Wabamun has not escaped the influence of man's activities in western Canada. In 1961, a thermal plant operated by Calgary Power Ltd. commenced production of electricity and in the process sent 432 million gallons per day of heated water into the lake.

In the past few years the word 'pollution' has become commonplace in newspaper articles and more recently it has not been unusual to hear of the thermal pollution of rivers and streams. However, less seems to have been known of the ecological effects of thermal pollution on lakes. Wheelock (1969), in conjunction with this study, produced a thesis on the phytoplankton ecology of Lake Wabamun. The present investigation was carried out in order to discover the extent of influence of the thermally heated zone. This lake is considered eutrophic particularly evident at the shallower east end where the heated effluent is discharged. Concomitantly, seasonal changes were followed in both the chemical and physical limnology in the heated area and in the unaffected part of the lake. A comparison was made between these areas in an attempt to discover what, if any, changes were brought about by the addition of thermally heated effluent into the lake. Biological changes were monitored also, with the greatest emphasis and concentration placed on effects of temperature on the egg production of the Rotifera. Little work was carried out

on the effects of heated water on fish because it was felt that their powers of locomotion would help them to avoid the heated area if they chose to do so, or in the case of the predator fishes, to pursue their prey into the thermally heated zone and then retreat from it should it be unfavourable.

It is hoped that the results of this study will help to elucidate some of the ecological effects of thermal pollution on the fauna of a lake, particularly the rotifers, and also to provide a foundation on which to base continuing limnological investigations in this most interesting field. The study may also be of some help in guiding further investigations dealing with changes which will be brought about by the opening of a second power plant on the lake late in 1970.

DESCRIPTION OF STUDY AREA

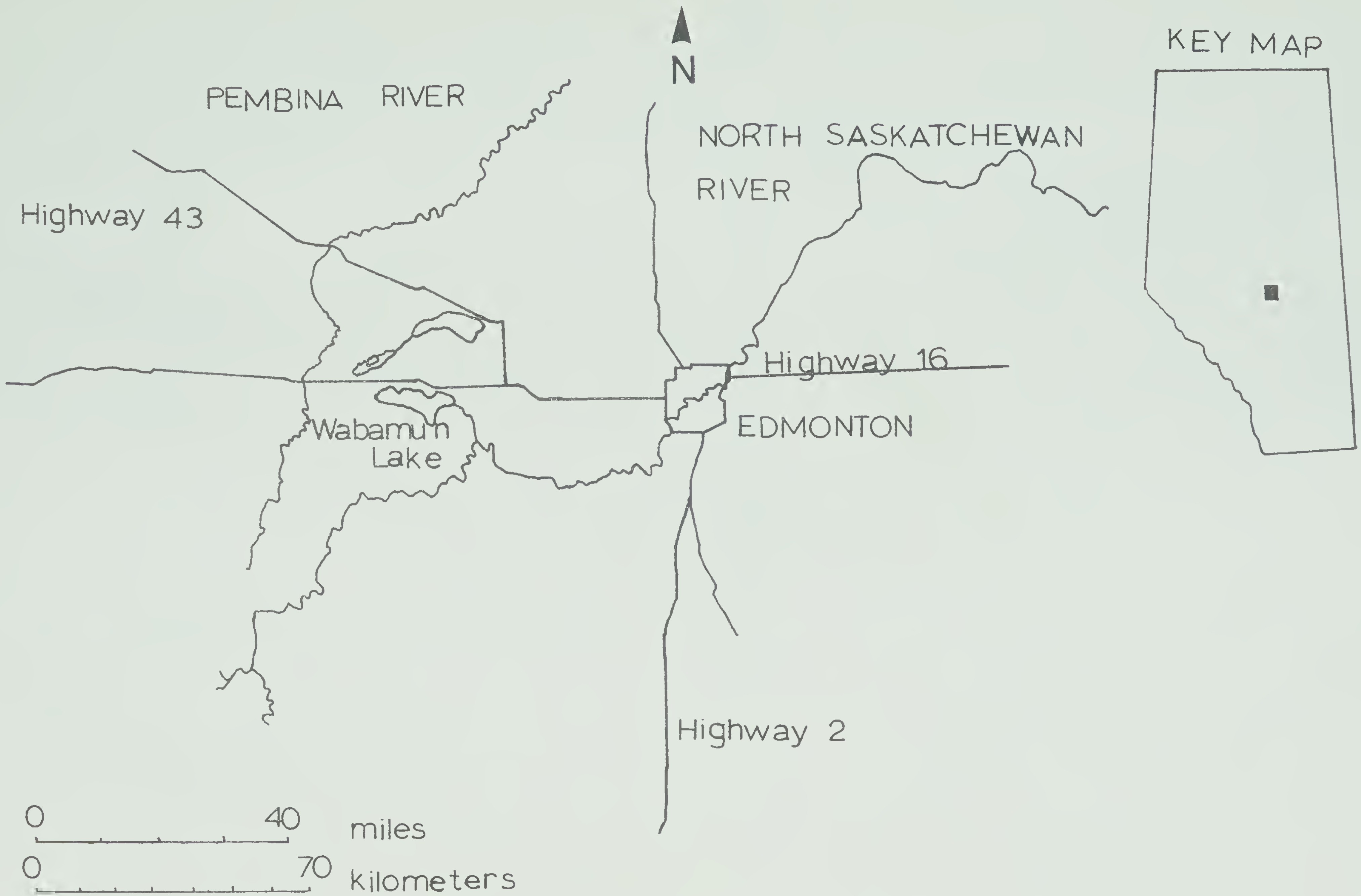
Lake Wabamun is situated about 50 km. west of Edmonton and approximately 1.5 km. south of Highway 16 (Fig. 1). The lake's geographic coordinates are from 114°26' to 114°44' west longitude and 53"30' to 53°34' north latitude.

Physiographically the area is an upland plain of low relief (Wyatt et al., 1930), with an elevation of 2371 feet at the lake surface. There is an eastward development of Tertiary sandstone and shales known as the Paskapoo formation extending between Isle Lake and Lake Wabamun (Rutherford, 1928; Wyatt et al., 1930). The massive sandstones of the Paskapoo are often 50 feet thick and are well exposed in the Fallis region and north of Seba Beach (Rutherford, 1928). Wabamun Lake is underlain by the Edmonton formation which is Cretaceous sandstone (Wyatt et al., 1930).

A coal seam, which is located about 90 feet above the level of the water on the north side of the lake, is worked by strip mining and has been in operation since 1913, and is at least 25 feet thick (Rutherford, 1928). On the south side of the lake the seam is at water level.

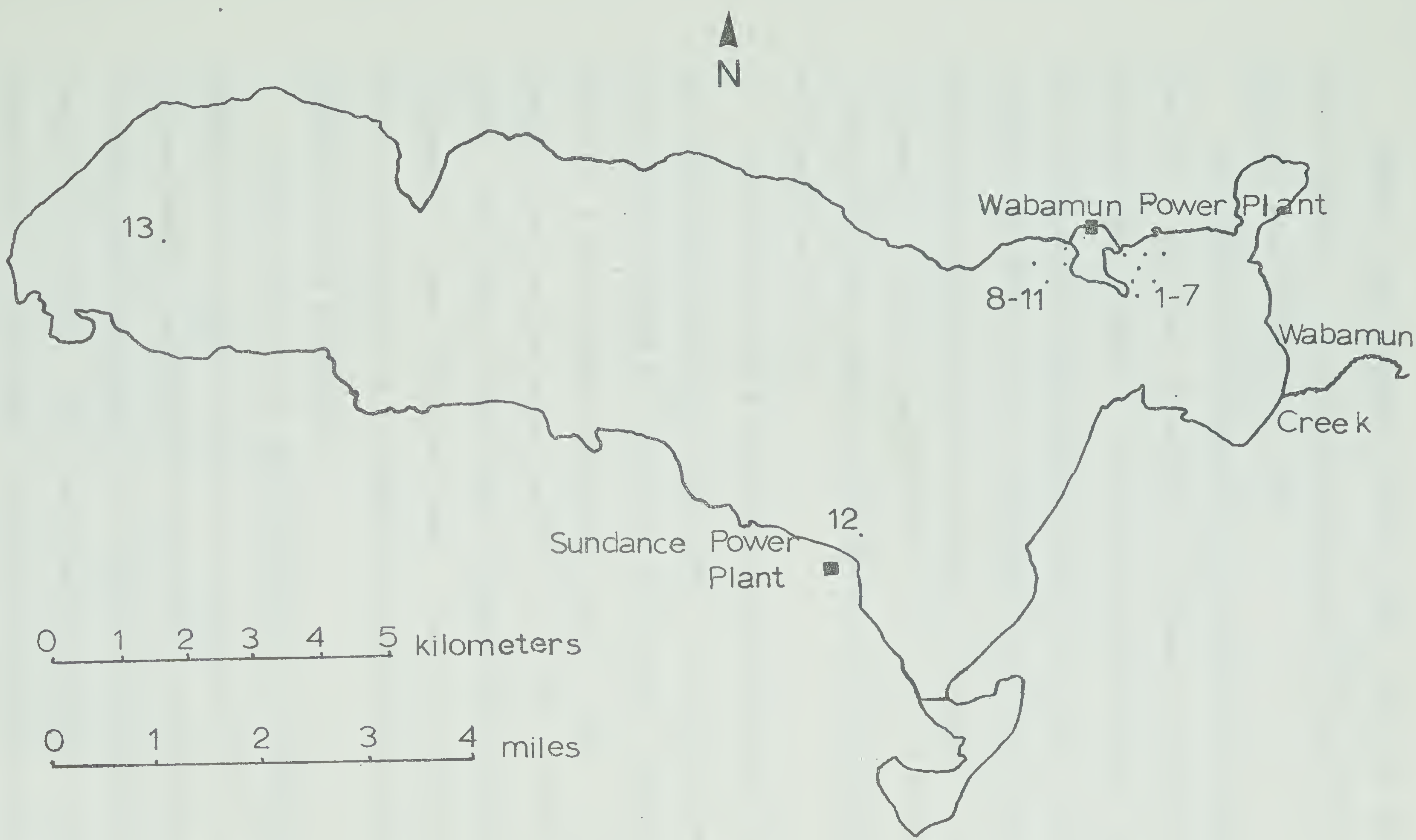
The topography of the area is undulating and rolling since glacial times and as a result the region contains a fairly large water surface in the form of lakes such as Lac Ste. Anne, Isle Lake and Wabamun Lake. The latter is drained intermittently into the North Saskatchewan River by a short channel called Wabamun Creek (Fig. 2). The North Saskatchewan River flows northward, joining other bodies of water before entering Hudson Bay. Lake Wabamun originally drained into the same channel that drains Isle Lake and Lac Ste. Anne, by means of an old channel that ran north and east from Lake Wabamun (Wyatt et al., 1930). This creek has since dried up.

Fig. 1.   Map of Edmonton area showing location of Lake Wabamun.



PEMBINA RIVER
Highway 43
N
NORTH SASKATCHEWAN
RIVER
KEY MAP
Highway 16
EDMONTON
Wabamun
Lake
Highway 2
0
40
miles
0
70
kilometers

Fig. 2. Map of Lake Wabamun showing location of sampling stations (1 - 13), and Wabamun Creek.


N
13.
Wabamun Power Plant
8-11
1-7
Wabamun
Creek
12.
Sundance Power
Plant
0 1 2 3 4 5 kilometers
0 1 2 3 4 miles

There is some evidence that Chip Lake, Isle Lake, and Lac Ste. Anne are all remnants of a continuous, long, narrow body of water with an east-west trend (Rutherford, 1930).

The climate of the Edmonton area is described as being cold temperate (Anon., 1969) and, in general, the Wabamun Lake district experiences the same type of weather. It is characterised by having long, bright, and moderately warm summer days and bright, cold, dry winter weather (Kendrew and Currie, 1955). The weather data for the study period were obtained from the meteorological station of the Dominion Dept. of Transport at Stony Plain which is approximately 15 km. east of Lake Wabamun. Table 1 shows the monthly means for temperature, total precipitation, and mean wind speed and direction.

The year 1968 had a mean summer temperature close to average mean but autumn temperatures were below normal. In 1969 the area had a very cold winter, warm and dry spring and early summer, followed by a cool wet fall with a mild November and December (Anon., 1969). A cold period in January, 1969 was the longest period of continuous sub-zero weather on record. The winter of 1969-70 was a comparatively mild one, and it was followed by a warm, fairly wet summer. About two-thirds of the average annual precipitation (18.64 inches) in the area falls during the growing season of spring and summer.

A large area of silt loam (wooded soil) is situated south of Lake Wabamun, with a small area north of the east end of the lake. One area of sandy loam is located south of Seba Beach in undulating rolling country with many grass sloughs and is too rough to be of much agricultural value (Wyatt et al., 1930). Only a small part of the area is cultivated, usually the black soil belt, with most of the farming being carried

Table 1. Some meteorological conditions for the Lake Wabamun Region, 1968-70. (Data from Department of Transport, Weather Office, Stony Plain.)

	1968											
					May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean Max. Temp.					61.0	66.9	72.9	65.2	58.9	48.1	35.8	7.6
Mean Min. Temp.					39.0	45.9	51.2	47.0	42.3	31.8	21.8	-3.6
Mean Temperature					50.0	56.4	62.1	56.1	50.6	40.0	28.8	2.0
Extreme Max. Temp.					77	80	86	79	75	63	48	30
Extreme Min. Temp.					23	33	43	36	31	23	-3	-32
Total Precipitation*					1.15	2.67	2.33	2.73	1.33	1.02	0.16	1.59
Total Snowfall*					0.0	Tr.	0.0	0.0	Tr.	4.4	1.6	15.9
Mean Wind Speed					9.0	NA	6.4	6.3	7.1	6.7	6.5	6.9
Prevailing Direction					NW	NA	NW	NW	NW	NW	SW	NW
	1969											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean Max. Temp.	-8.9	18.0	31.5	53.2	62.5	70.3	70.3	71.0	57.3	44.5	38.1	26.8
Mean Min. Temp.	-22.4	0.7	13.5	33.3	40.9	48.5	49.9	49.5	41.0	27.8	21.9	14.0
Mean Temperature	-15.7	9.7	22.5	43.3	51.7	59.4	60.1	60.3	49.2	36.2	30.0	20.4
Extreme Max. Temp.	39	31	47	71	83	86	86	81	78	63	59	41
Extreme Min. Temp.	-38	-19	-8	20	33	34	44	37	28	10	-10	-3
Total Precipitation*	0.65	0.76	0.30	0.92	1.38	1.39	3.62	4.90	3.24	1.20	0.81	0.50
Total Snowfall*	6.0	7.6	3.0	3.7	0.0	0.0	0.0	0.0	Tr.	5.2	8.1	4.9
Mean Wind Speed	5.3	5.3	6.5	8.1	7.2	7.2	7.0	6.9	7.4	6.8	7.1	7.1
Prevailing Direction	NW	E	NW	SE	NW	NE	NW	NW	NW	NW	SW	W
	1970											
	Jan.	Feb.	Mar.	Apr.	May	June	July					
Mean Max. Temp.	9.7	29.4	28.1	48.1	62.0	72.7	71.6					
Mean Min. Temp.	-4.8	13.6	11.5	29.3	40.3	52.6	52.9					
Mean Temperature	2.5	21.5	19.8	38.7	51.2	62.6	62.3					
Extreme Max. Temp.	43	46	51	57	81	92	85					
Extreme Min. Temp.	-37	-11	-14	19	31	44	47					
Total Precipitation*	0.69	0.65	1.01	0.17	0.58	4.75	4.32					
Total Snowfall*	6.9	6.5	7.8	1.3	0.2	0.0	0.0					
Mean Wind Speed	6.8	7.5	7.4	7.2	8.9	7.9	6.7					
Prevailing Direction	W	W	E	NW	SE	NW	NW					

*In inches.
Wind Speed in m.p.h.
Temperature °F.

out south of the lake.

The Wabamun Lake area is situated on the west side of the Boreal-Parkland Transition zone of Moss (1955). The dominant tree species in this region are the white or aspen poplar *(Populus tremuloides)* and the balsam or black poplar *(P. balsamifera)*. The white poplar is regarded as the climax species of the main parkland of Alberta (Moss, 1932).

The entire poplar vegetation of central and northern Alberta is regarded as an association within which white and balsam consociations occur (Moss, 1932). In the Wabamun location species characteristic of both consociations are found.

MATERIALS AND METHODS

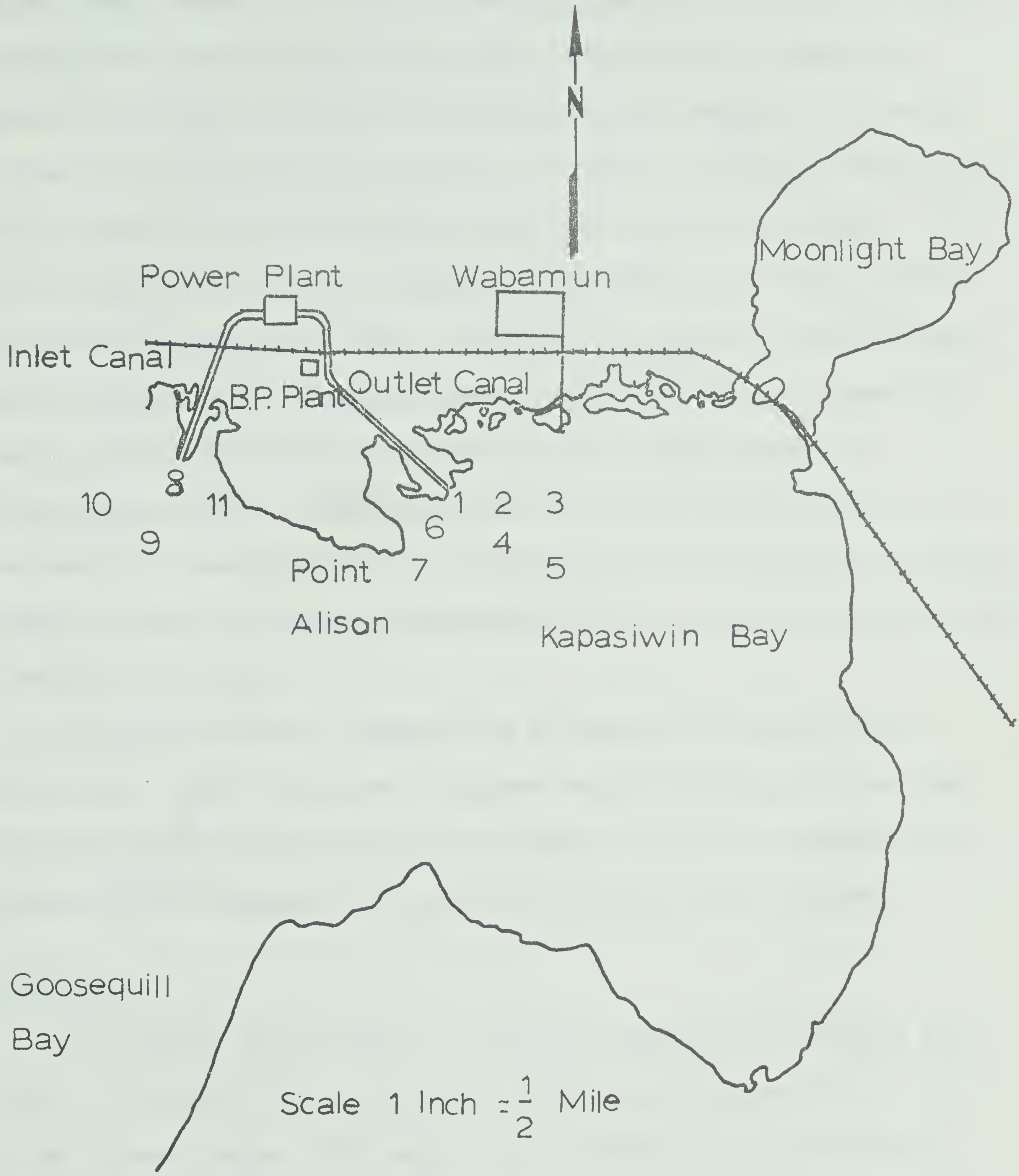
Physical and Chemical

Water samples were analysed chemically and physically every week during the summers of 1968 and 1969, monthly during the summer of 1970, and twice monthly during the fall of 1968 and winter of 1968-69 (Appendix). The water samples were taken with a Kemmerer two-litre water bottle at stations 4 and 13 (Figs. 2 and 3). In addition, water samples were taken from the inlet and outlet canals during the winter and summer of 1969 using the same instrument. Occasional samples were also taken from the Building Products (B.P.) plant (Fig. 3).

The water samples were analysed using a Hach model DR-EL Portable Water Engineer's Laboratory Kit. In addition, duplicate samples were analysed by the Alberta Provincial Analyst, Edmonton. Dissolved oxygen was determined using the modified Azide-Winkler method of the Hach Kit. Five-day Biochemical Oxygen Demand (B.O.D.) determinations were made by the Environmental Health Services Laboratory, Edmonton. The specific conductance of the water was measured with a Beckman RB 3 battery-operated Solu Bridge adjusted to 25 C. Hydrogen ion concentration was determined using the Hach Kit and a Beckman pH meter.

On August 29, 1968, the water velocity of the outlet canal was recorded using a Gurley No. 665 Direct Reading Current Recorder. Light penetration was recorded at stations 4 and 13 on April 9 and June 27, 1969 using a Submarine Photometer series 268 WA. Percentage transmission was recorded with a Transmissometer, Model 410-BR, and underwater sensor Model 411. Air temperatures were recorded using a mercury thermometer. Water temperatures were recorded using a Model ET 100 Interchangeable

Fig. 3. Map of the east end of Wabamun showing location of sampling stations (1 - 11) in relation to the inlet and outlet canals.


N
Power Plant
Wabamun
Moonlight Bay
Inlet Canal
B.P. Plant
Outlet Canal
8
10
11
1
2
3
6
4
9
Point
Alison
7
5
Kapasiwin Bay
Goosequill
Bay
Scale 1 Inch = 1/2 Mile

Range Linear Thermometer (Applied Research, Austin). Horizontal temperature profiles were recorded using the ET 100 thermistor linked to a Rustrak Miniaturised Automatic Chart Recorder with amplifier and using a Trav-Electric Model 50-160 Inverter as a source of power. On August 5, 1969, a Ryan Model D-30 Thermograph with a temperature range of 0 - 30 C., was installed east of the B.P. plant in the outlet canal (Fig. 3) and was removed on August 28, 1969. On August 17, 1969, the surface temperature of the lake was recorded by means of remote sensing equipment on board a North Star aircraft operated by the National Aeronautical Establishment, Ottawa, under the direction of Dr. Neil de Villiers. On the same date relative humidity was measured at one meter above the water surface by means of a sling psychrometer and wind speed was recorded using a portable wind gauge.

During the winter of 1968-69 ice thickness was measured with a meter stick. Water levels were recorded regularly during the ice-free periods of 1968-69 by measuring the changes in level on a marked white board which was attached to the west side of the wharf at Wabamun.

Biological

Mud samples were collected at monthly intervals or sometimes more often, at stations 4 and 13 from June 1968 through August 1969, using a 225 cm^2. Ekman dredge. The samples were returned to the laboratory in plastic bags and were then washed through two brass mesh screens. The uppermost screen was a 0.841 mm. mesh and the lowermost was a 0.595 mm. mesh Canadian Standard Sieve. The organisms found in the residue were preserved in 70% alcohol. Subsequently, the organisms were counted and identified.

Ecological analyses of the macrophyte vegetation were mainly carried out by members of the Botany Department during the summers of 1969 and 1970 and are only briefly mentioned in this study.

During August 1968, some netting of fish was carried out at various locations using gill and seine nets.

In order to sample the surface fauna a neuston net modified from the design of David (1965) was built (Plates 1 and 2). The floating sampler had dimensions approximately half the size of the six foot long sea-going model of David. The net used in the lake had a No. 20 bolting silk with the cup from a Wisconsin net attached to the end of the net for easy removal. The net was supported upon the wooden crossbeams by means of a brass bar. The apparatus was used for sampling during the summer, fall and early winter of 1969, in the inlet and outlet canals and at station 12 (Sundance). The instrument was launched from an anchored boat and towed along the water by means of a winch and a long nylon rope, the winch being placed 100 m. away on the bank or shore and the net pulled onto the shore by winding up the winch. In each case a stop-watch was used to time the 100 m. haul. The net samples taken from the canals could not be directly compared with those of station 12 unless a correction was made to allow for the currents. The samples taken for station 12, on the other hand, were collected on undisturbed (apart from wind action) lake water. The neuston net at the mouth had an area of 200 cm^2. (25x8 cm^2.) so that in undisturbed water a 100 m. tow would sample a total of 2.0 m^3. of water by volume. Obviously, with an added current a greater volume of water would be sampled. For example, a current near the bridge of both canals had an average velocity of 0.2 m/sec., and a 100 m. tow which took 4 minutes would in fact be sampling about 150 m. (the extra 50 m. being attributed to

Plate 1. Neuston net mounted on wooden crossbeams. Also shown are winch and nylon rope (by R. Egedahl).

Plate 2. Neuston sampler afloat, showing attachment of net to wooden crossbeams (by R. Egedahl).

the current passing through the net in 4 minutes) although the net had gone only 100 m. in actual measured distance. The actual volume of water passing through the net in this instance was 3.00 m^3.

In all three areas the samples taken were washed into labelled jars and brought up to 200 ml. with distilled water in the case of the samples to be examined *in vivo*; 200 ml. of 90% alcohol was added to the remaining samples. In the laboratory three separate 1 ml. sub-samples were taken immediately after thoroughly shaking the jar, and placed in a 5 ml. cell with 4 ml. of distilled water added to each sub-sample. All the Rotifera and Protozoa (the latter examined in fresh unpreserved samples) were counted and identified using an M 40 Wild Inverted Microscope. The average number for the three sub-samples was taken and the total numbers of organisms in each sampling area were calculated and tabulated.

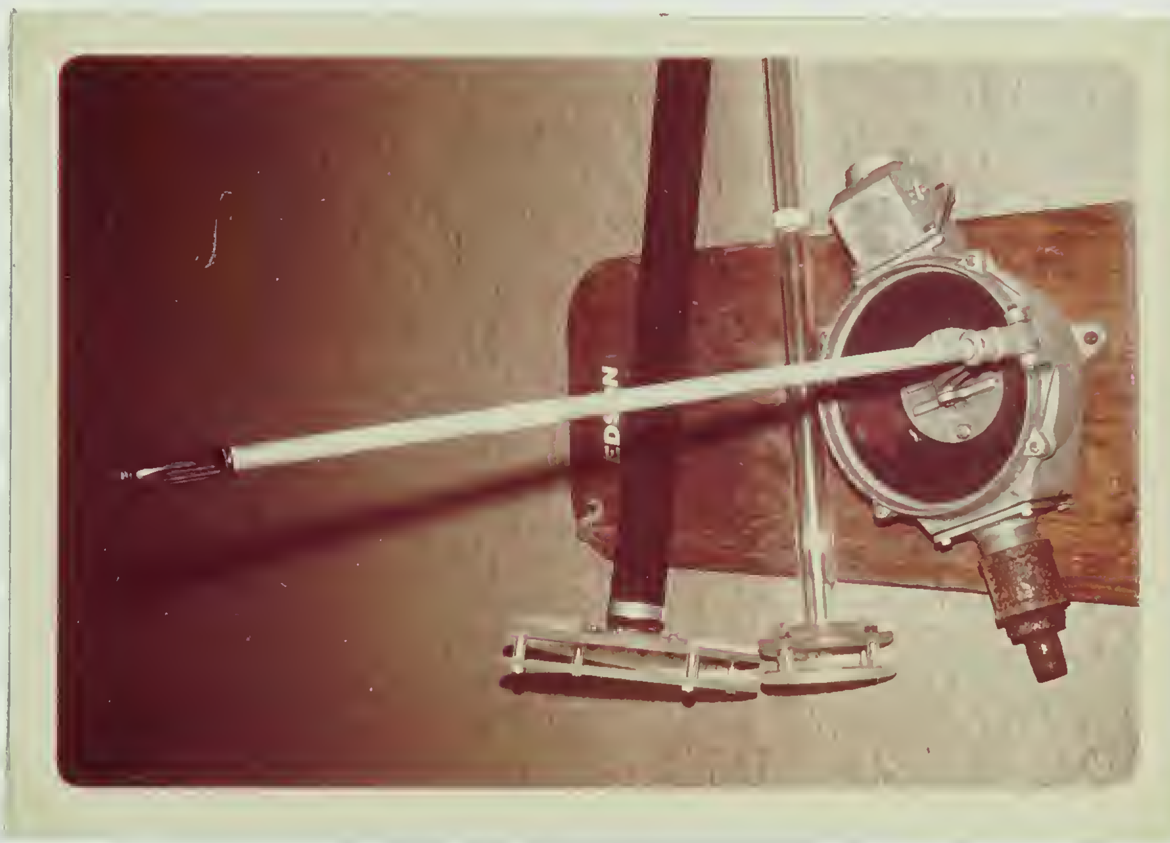
In an attempt to discover the effects of temperature and currents on the distribution of plankton organisms (particularly the Rotifera) and also to compare the heated and unheated areas, a series of transects radiating out from the inlet and outlet canals (stations 1 - 11, Fig. 3), with a control station at Sundance (station 12), were used. This intensive sampling program began on January 31, 1970, and was completed on August 27, 1970. To carry out this study an Edson diaphragm pump (Plates 3 and 4) was used as it was found to have some advantages over other sampling methods, such as its ease of manipulation and carrying and the fact that the flexible hose can be readily lowered to the desired depth in order to sample a localised area. Sampling was carried out twice monthly during winter and early spring and weekly from late spring onwards.

From January to mid-May a plexiglass flange 12 inches (30.5 cm.)

Plate 3. Edson diaphragm pump with flexible hose and 6 inch (15.25 cm.) diameter plexiglass flange (by R. Egedahl).

Plate 4. Edson diaphragm pump showing the 12 inch (30.5 cm.) and 6 inch (15.25 cm.) plexiglass flanges. The flange halves are separated by a 1 inch (2.5 cm.) space through which water is drawn by suction (by R. Egedahl).


EDSON


EDSON

with a 1 inch (2.5 cm.) space between the flange halves was used with a 2 inch (5.0 cm.) rubber hose. Two lengths of rubber hose were used on the intake and these were joined by male and female couplings and the samples were taken at 0, 0.5, 1.0, and 1.5 m. depths at the various stations. One 3 foot (90 cm.) length of hose was attached to the outlet of the pump and the end of the pump was directed into the mouth of a No. 20 bolting silk Wisconsin net while the pumping was in progress. Pumping was continued until 10 litres of water had passed through the pump and net into a calibrated container. This procedure was carried out at each depth at the 12 stations and in each case the organisms were transferred, by washing with 95% alcohol, from the net into labelled snap-cap vials until 50 ml. of concentrated sample was obtained. For comparative purposes an occasional larger sample, e.g., 20 or 30 litres, was taken from the lake with the pump.

It was decided that a more flexible rubber hose with a smaller diameter would be more effective than the 2 inch (5.0 cm.) diameter hose and so in mid-May a plexiglass flange with a 6 inch (15.25 cm.) diameter, with a 1 inch (2.5 cm.) space between the flange halves, was attached to a length of hose with a diameter of 1 inch (2.5 cm.). The lengths of hose were again joined by male and female couplings and precisely the same sampling procedure was carried out at the same depths and at the same 12 stations used with the larger diameter rubber hose. The number of depths sampled in the heated zone by this method gradually decreased as rapid and extensive weed growth continued during the summer until some stations could only be sampled at the surface.

The mean coefficient of variation for the method used to enumerate numbers of rotifers during the investigation period was 18.3%.

Edmondson (1946) developed a method for estimating the rate of change of population which was used in this study. To calculate the rate of change, numbers for two successive sampling dates are taken. The difference in numbers between the two sampling dates is expressed as a percentage of the initial number. This percentage, divided by the number of days between the two successive sampling dates, gives the rate of change in terms of per cent/day. The procedure is repeated from one sampling date to the next. Population increases are given a positive sign; population decreases are given a negative sign.

PHYSICAL CHARACTERISTICS

Morphometry

Wabamun Lake is oriented in an east-west direction which is in line with the prevailing winds in the area. An exposed, rocky shore in Goosequill Bay (Plate 5) contrasts strikingly with a sheltered, heavily weeded shore characteristic of the richly silted Kapasiwin Bay (Plate 6).

Wabamun Lake has a surface area of 82.5 km^2., having a maximum length of 19.2 km. (Table 2). A map (Fig. 4) showing the contours of the lake indicates the relief from east to west to be relatively gentle. The east end is shallowest, and this fact may be attributed to the build-up of sediments caused by the prevailing west or north-west winds. The lake is shallow, having a maximum depth of 11.6 m.

The shoreline development, which is a measure of the irregularity of a shoreline, of Lake Wabamun is 1.83. This value represents relatively regular shoreline compared to the more irregularly shaped Beaver Lake which has a value of 4.18 (Pinsent, 1967). Other morphometric measurements are found in Table 2.

The water level in Lake Wabamun varied by about 30 cm. during the course of the study (Fig. 5), the greatest rise in level being recorded in spring and being attributed to melted snow and ice. The lake level dropped gradually during the summer periods mainly through evaporation. An increased rate of evaporation occurs in the heated zone because of the elevated temperatures and this phenomenon is visibly noticeable in winter when the evaporating water on contacting very cold air becomes a thick fog in this area. However, despite the added rate of evaporation since the opening of the power plant in 1961 the level of

Plate 5. Exposed rocky, east shore of Goosequill Bay.

Plate 6. Sheltered heavily weeded north shore of Kapasiwin Bay. The mouth of the outlet canal is located on mid-right-hand side of the photograph.

Table 2. Some morphometric measurements of Wabamun Lake. (South end of Goosequill Bay is cut off by a railroad causeway and is no longer an effective part of the lake and is omitted here.)

Surface area	32.5 km.^{2}
Shoreline length	57.3
Shoreline development	1.83
Volume	0.455 km.^{3}
Maximum depth	11.6 m.
Mean depth	5.4 m.
$\frac{\text{Mean depth}}{\text{Maximum depth}}$	0.47
Maximum effective length	19.2 km.
Maximum effective width	6.6 km.
Mean width	4.3 km.
Drainage basin	372.4 km.^{2}
Elevation	722.7 m.

Fig. 4. Hydrographic map of Lake Wabamun. (Provincial Government of Alberta)

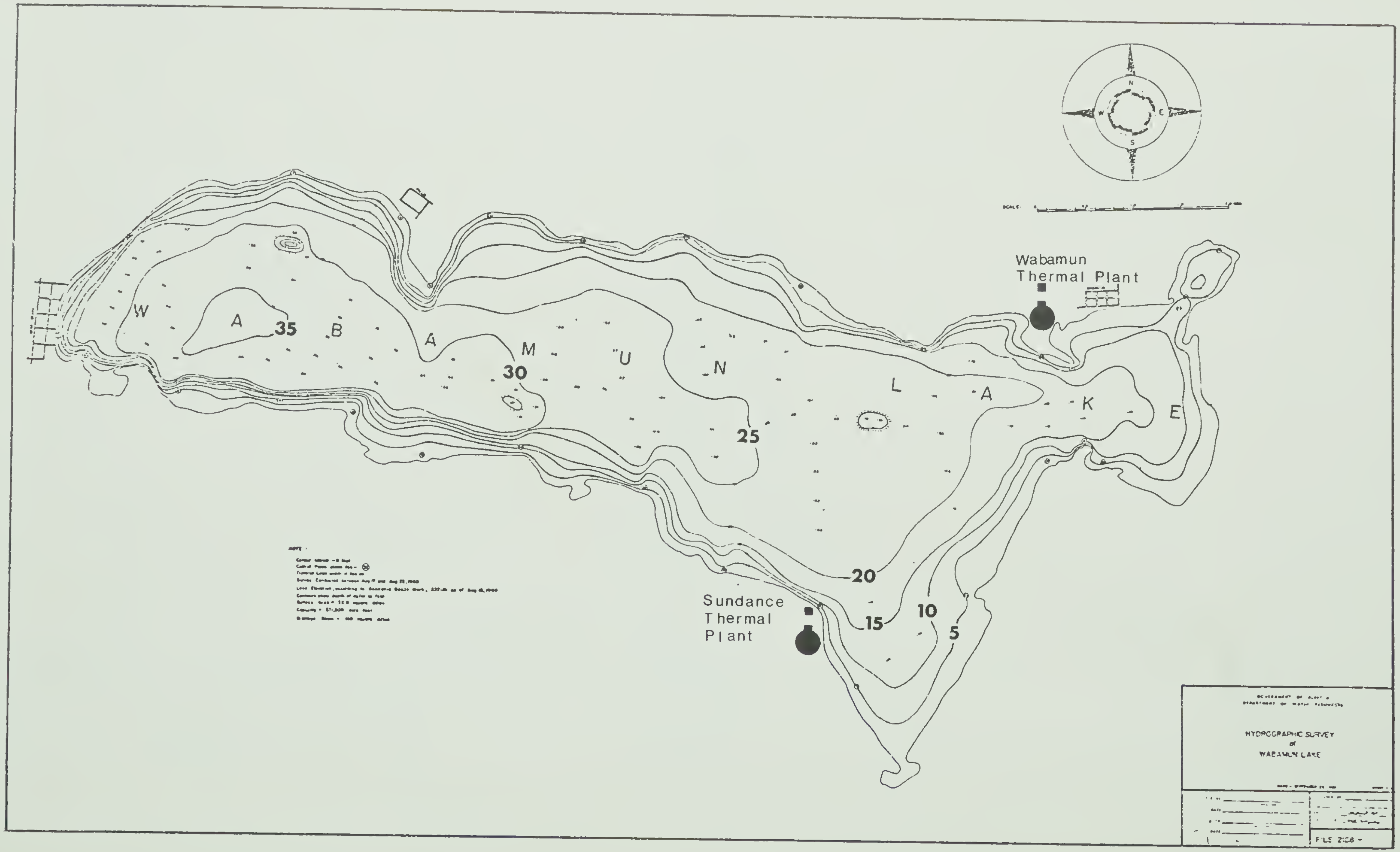
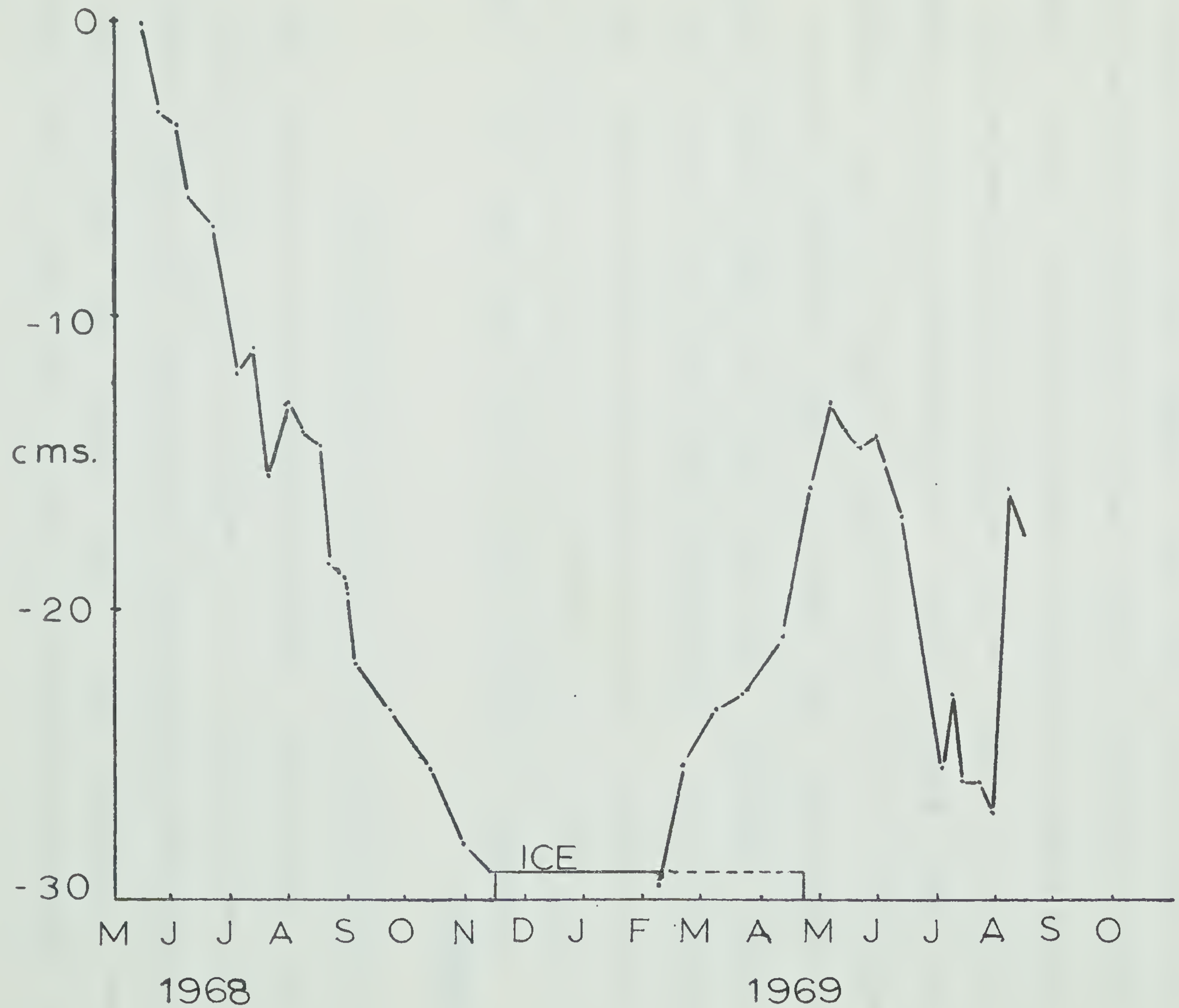

W A B A M U N L A K E
35
30
25
20
15
10
5
Wabamun
Thermal Plant
Sundance
Thermal
Plant
N
S
E
W
HYDROGRAPHIC SURVEY
of
WABAMUN LAKE
FILE 2128 -

Fig. 5. Water level fluctuations in Lake Wabamun, 1968-1969. Measurements taken at Wabamun Town Pier. Ice present only part of winter due to heated water.


0
-10
cms.
-20
-30
ICE
M J J A S O N D J F M A M J J A S O
1968
1969

the lake has not dropped and in fact that water level is more constant than in comparable lakes in central Alberta such as Pigeon Lake, Gull Lake and Sylvan Lake where the lake levels have been dropping steadily since about 1954 (Fig. 6). It remains to be seen if the second power plant on Lake Wabamun (commenced production late in 1970) will alter the fairly constant levels the lake is now experiencing.

Turbidity

Turbidity is greatest during the open water season (Fig. 7, Table 3), and the high summer readings may be attributed to the presence of increased numbers of phyto- and zooplankton organisms (Ruttner, 1963; Hutchinson, 1967). Strong winds or heavy rains will also add to the turbidity (Hutchinson, 1967) and, in fact, the highest reading (46 JTU) was recorded after a wet stormy day. Under ice suspended material contributing to the turbidity gradually settles out and the transparency of the water increases slowly. In the heated zone the lake is unfrozen in winter and in this area the turbidity is also low because of the relative scarcity of planktonic organisms during that period. The mean value for turbidity at station 4 was 19.1 JTU which, as expected because of the lack of an ice cover there, is higher than the overall mean of 17.1 JTU at station 13. The mean winter turbidity under ice at station 13 was 5 JTU (in the period from Dec. 6 to April 28) compared to the value of 6 JTU at the unfrozen station 4.

Transparency

The range of Secchi disc readings are given in Table 4. The highest readings were recorded on June 3, 1970, during a period of very warm, sunny and windless weather. The phytoplankton content of the water

Fig. 6. Water level fluctuations in Lake Wabamun, Pigeon Lake, Gull Lake and Sylvan Lake, 1908-1969. (Provincial Government of Alberta)


WATER SURFACE ELEVATION IN FT
WABAMUN LAKE
PIGEON LAKE
GULL LAKE
SYLVAN LAKE

Fig. 6

Fig. 7. Comparison of changes in turbidity in surface water at stations 4 and 13, 1968-1969.

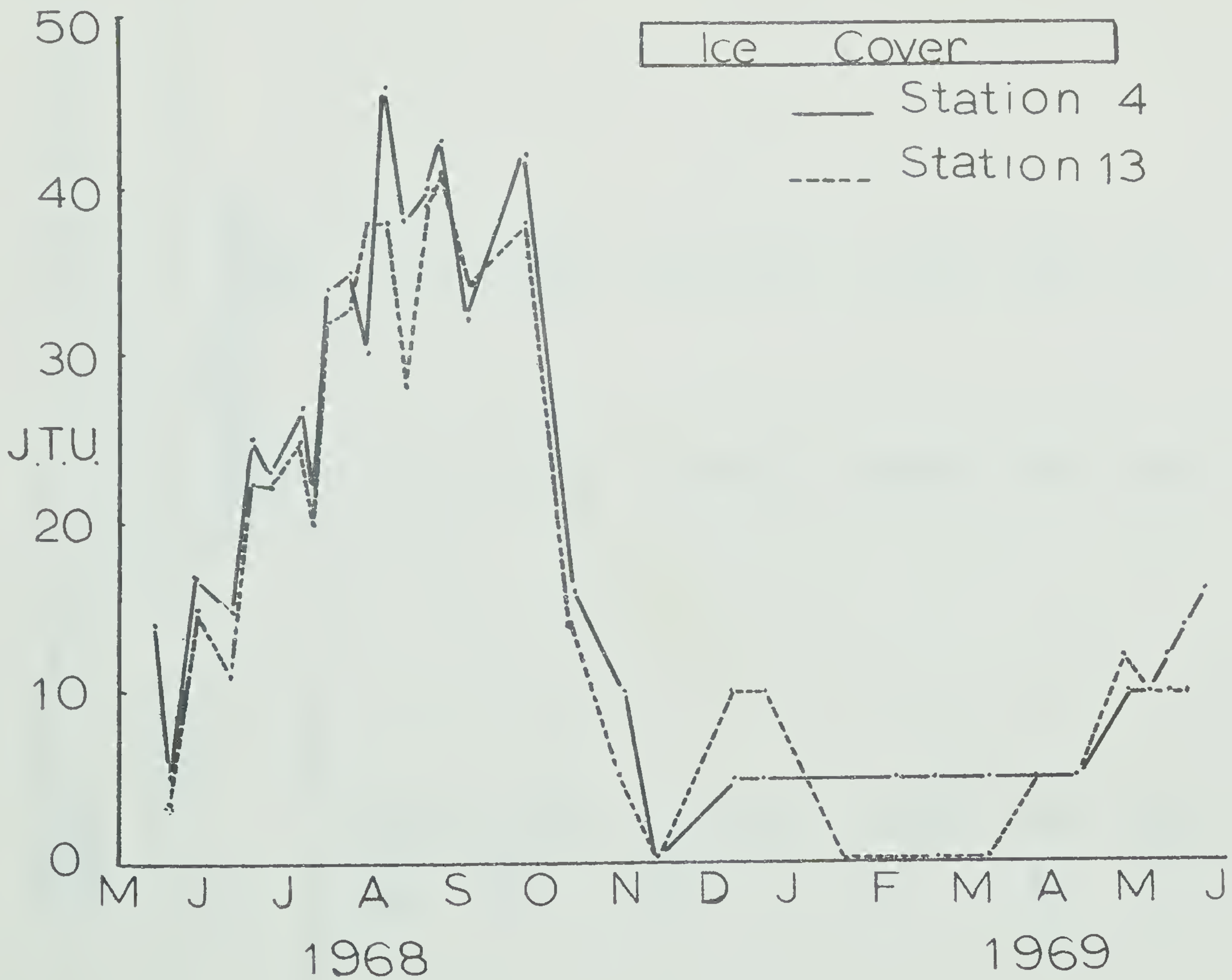

50
40
30
J.T.U.
20
10
0
Ice Cover
Station 4
Station 13
M J J A S O N D J F M A M J
1968
1969

Table 3. Turbidity at Stations 4 and 13, in Jackson Turbidity Units, 1968-69.

Year	Date		JTU (Heated) #4	JTU (Unheated) #13	
1968	May 15		14	--	
	" 22		5	3	
	" 30		17	15	
	June 11		15	11	
	" 18		25	23	
	" 26		23	23	
	July 3		27	25	
	" 9		22	20	
	" 16		34	32	
	" 23		35	33	
	" 31		30	38	
	Aug. 6		46	38	
	" 13		38	28	
	" 21		40	39	
	" 27		43	41	
	Sept. 4		32	34	
	" 27		42	38	
	Oct. 12		16	14	
	" 30		10	5	
	Nov. 11		0	0	
	Dec. 6		5	10	
	" 19		5	10	
1969	Jan. 17		--	0	
	Feb. 5	Ice-free period	5	0	Ice-cover period
	" 19		5	0	
	Mar. 8		5	0	
	" 26		5	5	
	Apr. 9		5	5	
	" 28		10	12	
	May 6		10	10	
	" 13		12	10	
	" 20		14	10	
	" 27		16	15	

Table 4. Secchi disc readings, 1970

Date	Location	Depth
May 14	#3	2.0 m.
	Inlet	2.0 m.
	Outlet	1.0 m.
May 21	#4	1.3 m.
	#5	1.3 m.
	#8	2.0 m.
	#9	1.7 m.
	#12	1.0 m.
June 3	#3	3.0 m.
	#8	3.0 m.
	#9	3.1 m.
	#12	3.5 m.

was low at this particular period which was also important in contributing to the transparency. The Secchi disc readings are only an approximate index of transparency and are influenced by local weather conditions (Welch, 1948).

The Secchi disc readings measured for Lake Wabamun were, in general, higher than those recorded by Kerekes (1965) in five more shallow lakes in Alberta. Pinsent (1967) found the Secchi disc visibilities of Lac La Biche and Beaver Lake to vary between 1.5 and 2.0 metres.

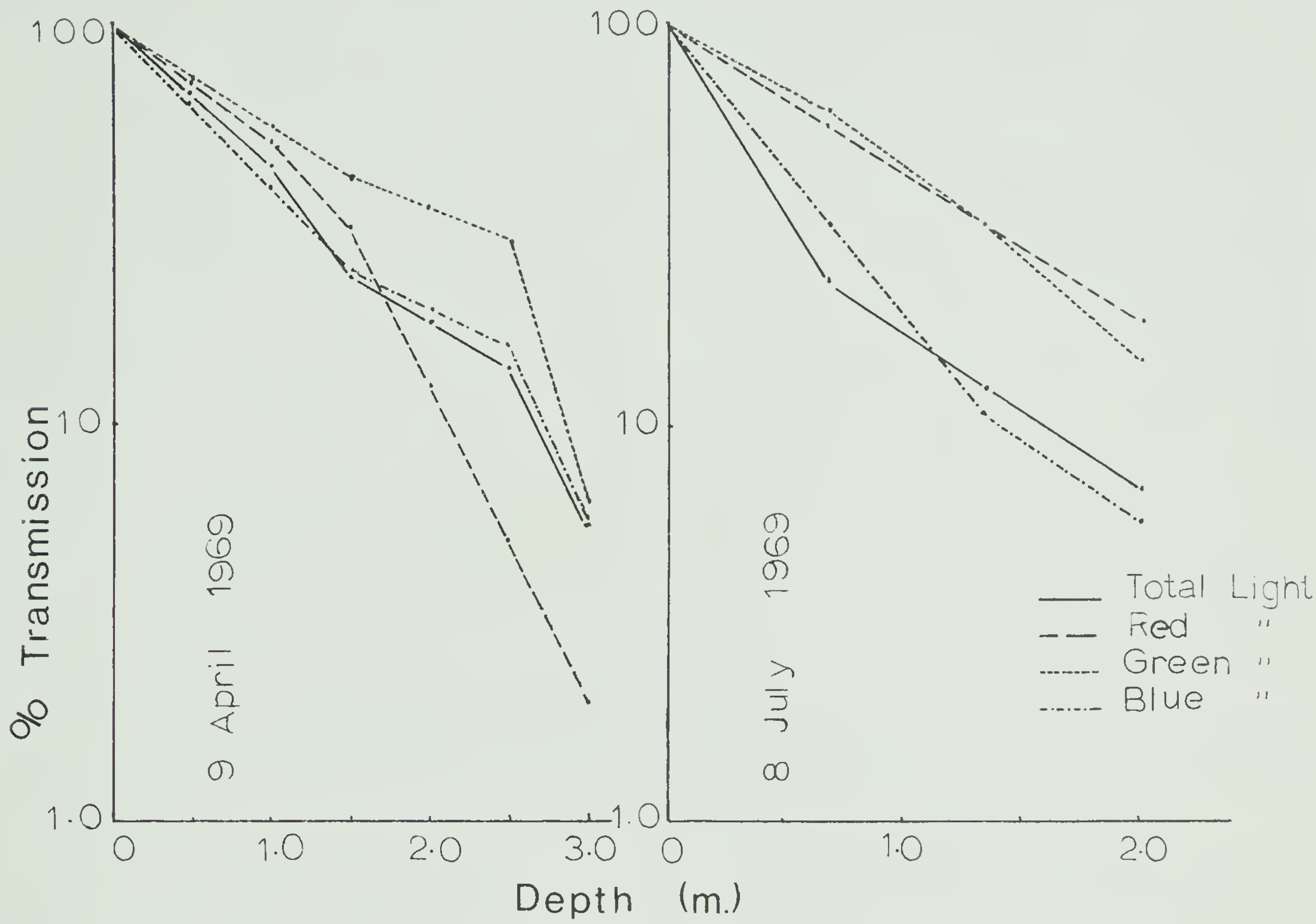
Light Intensity

The light intensity (in per cent transmission) was measured towards the end of winter (April 9, 1969) and again in summer (July 8, 1969) at stations 4 and 13 (Figs. 8 - 10). The large differences in the relative transmission of light of different spectral qualities seen in the graphs is influenced by many factors, including differences in suspended materials, amount of phytoplankton, etc. (Greenbank, 1945).

In winter, Lake Wabamun has relatively clear water and under these conditions light in the green portion of the spectrum is transmitted in the greatest amount (Figs. 8 - 10). Water is clearer under the ice at station 13 than in the open water at station 4, and hence the vertical attenuation is much reduced at station 13.

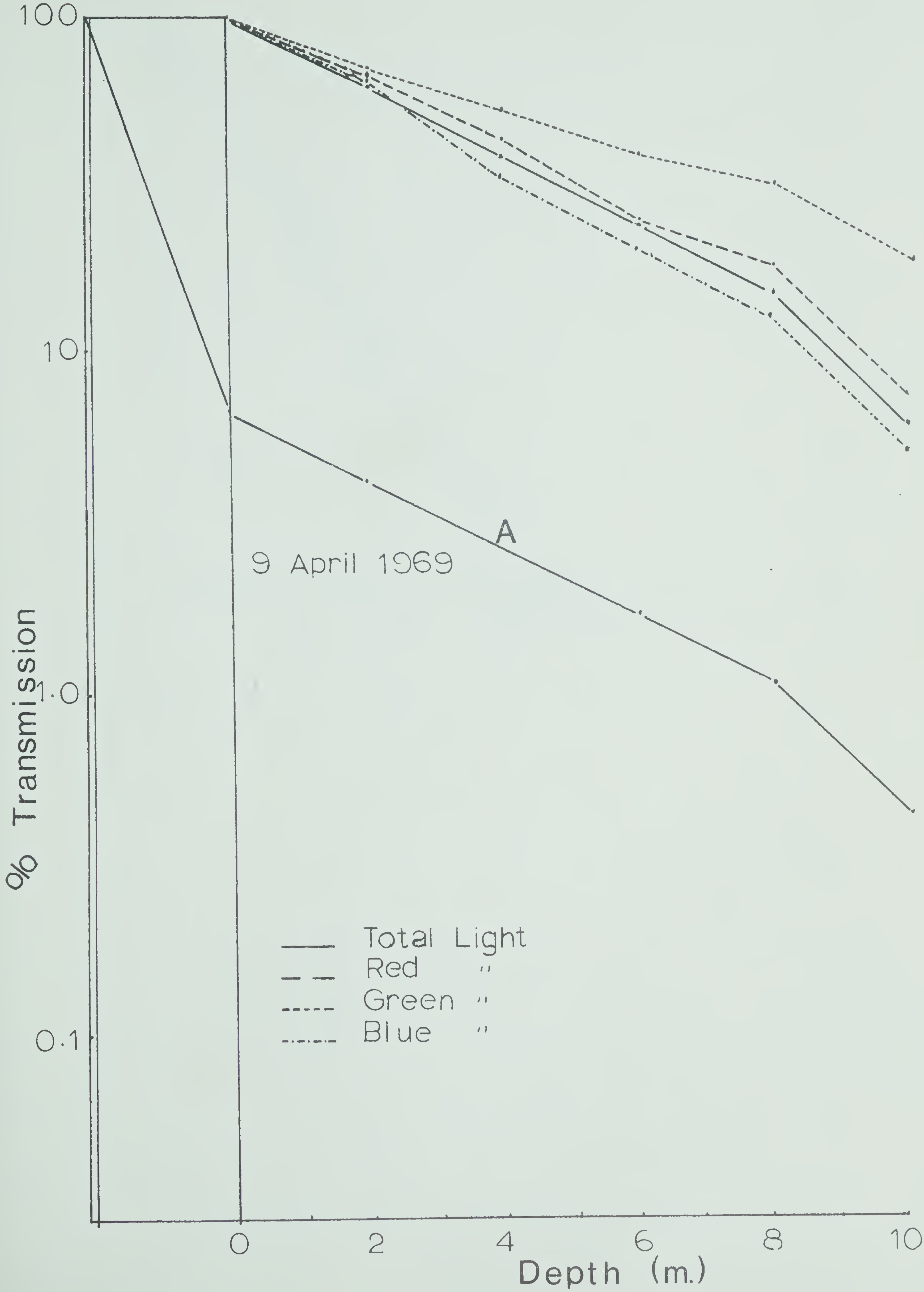
Because of the increase in phytoplankton and turbidity the water of Lake Wabamun is less transparent in summer. At this time there is a shift toward greater relative penetration in the longer wavelengths (red). Greenbank (1945) mentions that this kind of pattern is usual in less transparent waters. In open water there is also a surface loss of light in addition to the loss of light in the water itself. Clarke (1939)

Fig. 8. Character of transmission of red, green, blue and total light at station 4, April 9, 1969 and July 8, 1969.



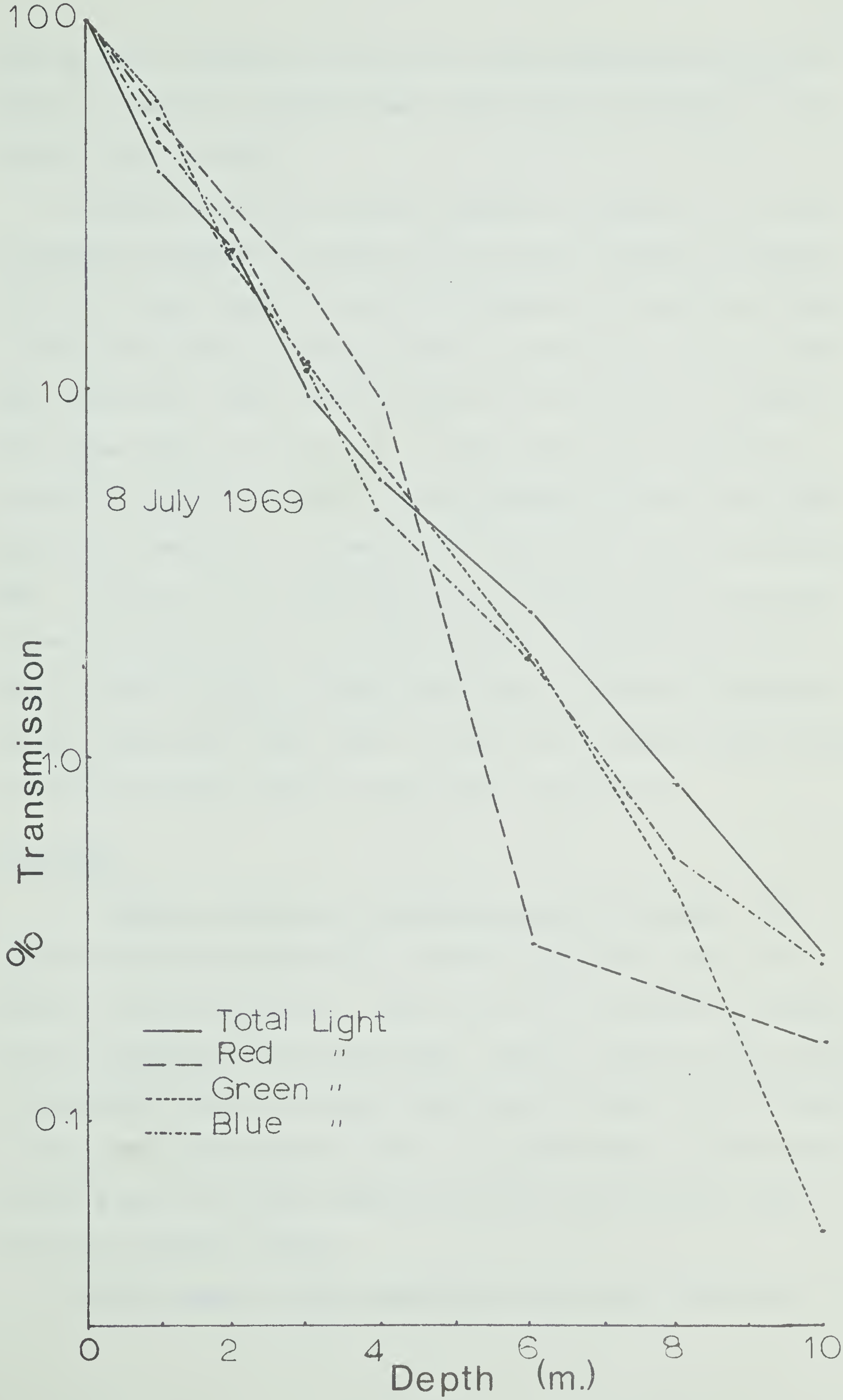
100
10
1.0
% Transmission
9 April 1969
0
1.0
2.0
3.0
100
10
1.0
8 July 1969
0
1.0
2.0
Depth (m.)
Total Light
Red "
Green "
Blue "

Fig. 9 . Character of transmission of red, green, blue and total light at station 4, April 9, 1969. Line A represents the transmission of total light through the overlying snow and ice on April 9, 1969.



100
10
1.0
0.1
% Transmission
0
2
4
6
8
10
Depth (m.)
A
9 April 1969
Total Light
Red "
Green "
Blue "

Fig. 10. Character of transmission of red, green, blue and total light at station 13, July 8, 1969.


100
10
1.0
0.1
% Transmission
8 July 1969
Total Light
Red "
Green "
Blue "
0
2
4
6
8
10
Depth (m.)

mentions that a fraction of this loss is due to reflection and the remainder is caused by a proportionately high rate of extinction in the uppermost layer of water.

In order to make the readings comparable in Figures 8 - 10, all the uppermost readings (just under the air-water interface in Figures 8 and 10, and just under the ice-water interface in Figure 9) are taken as 100% and the lines in the graph show the attenuation of the visible light and the red, green, and blue bands of the spectrum. In Figure 9, line A shows that only 5.7% of the visible light actually penetrated through the snow and ice cover if the percentage of light getting into the water is compared to the amount of incident light above the snow-ice cover. Anderson (1970) reported that 16% of incident light penetrated ice and snow cover (1 m.) on a lake in Alberta. This snow cover was about the same thickness as that recorded for Lake Wabamun (see later). Obviously, much less light enters the water in the unheated lake through a snow-ice cover than enters a heated area of open water.

Temperature

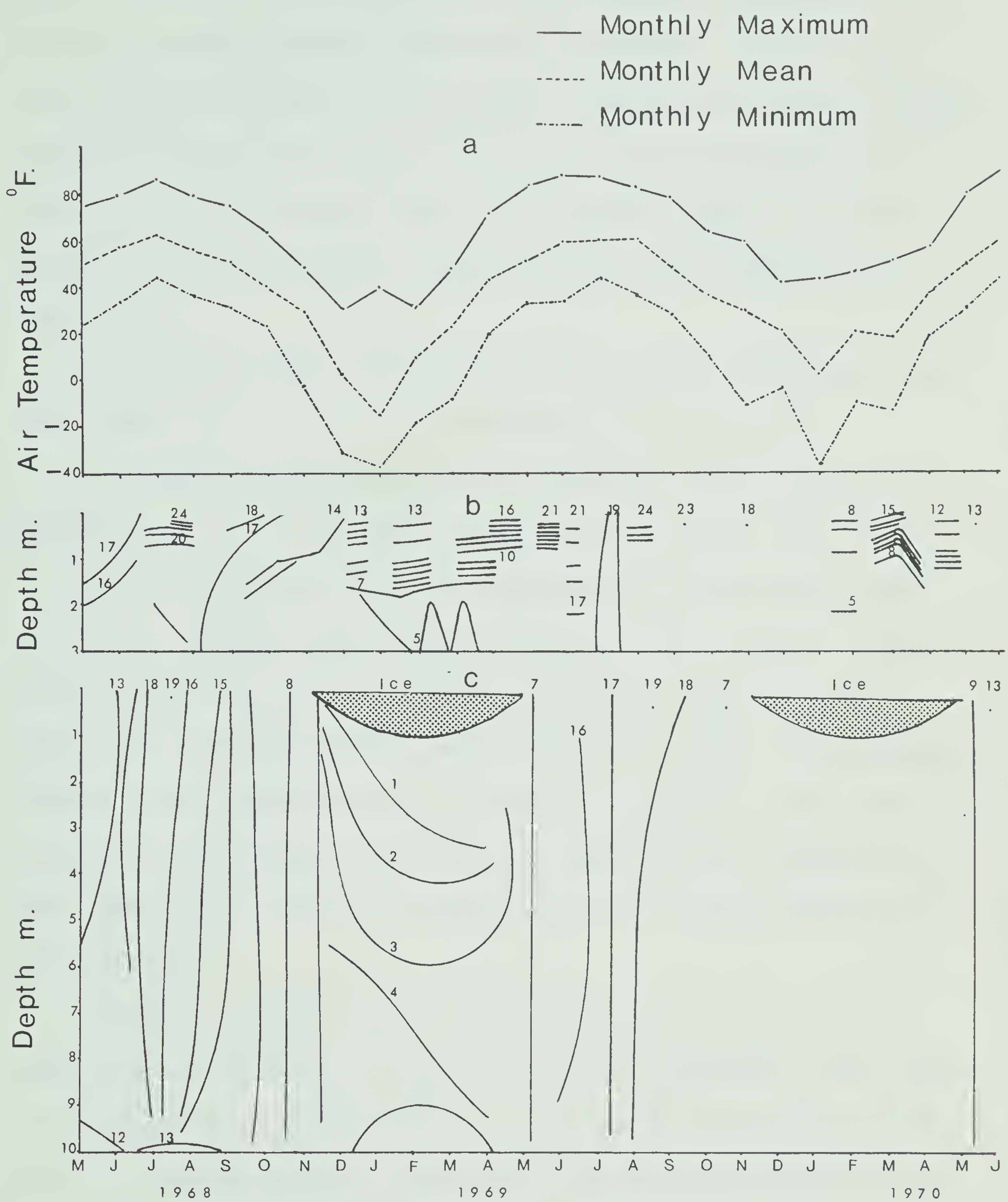
1. General conditions in the unheated part of the lake. The unheated area of Lake Wabamun has a dimictic temperature cycle. The period of ice cover (from Nov. - April, Fig. 11) lasts about six months and the ice-free period about the same. However, because of the addition of heated water, part of the lake remains open all year. The lake might be said to be an open system all year, not approaching a closed system for half a year as do other unaffected (by heat input) typical lakes of this area (Nursall, 1969).

Seasonal changes in lake temperature follow those of the air

Fig. 11. *a.* Monthly changes in air temperature showing maximum, minimum and mean ranges.

b. Changes in water temperature at various depths at station 4, May 1968 to June 1970.

c. Changes in water temperature at various depths at station 13, May 1968 to June 1970.



Monthly Maximum
Monthly Mean
Monthly Minimum
a
Air Temperature °F.
80
60
40
20
0
−20
−40
b
Depth m.
c
Ice
Depth m.
M J J A S O N D J F M A M J J A S O N D J F M A M J
1968
1969
1970

(Fig. 11, Table 1). In general, the unheated part of the lake is too shallow to undergo thermal stratification in summer. In winter ice cover protects the lake from the effects of winds and an inverse stratification is set up at 0 C. just under the ice and increasing until it reaches 4 C. in the deepest water at the bottom. During this winter stagnation (Ruttner, 1963) the bottom mud may have a temperature in excess of 4 C.

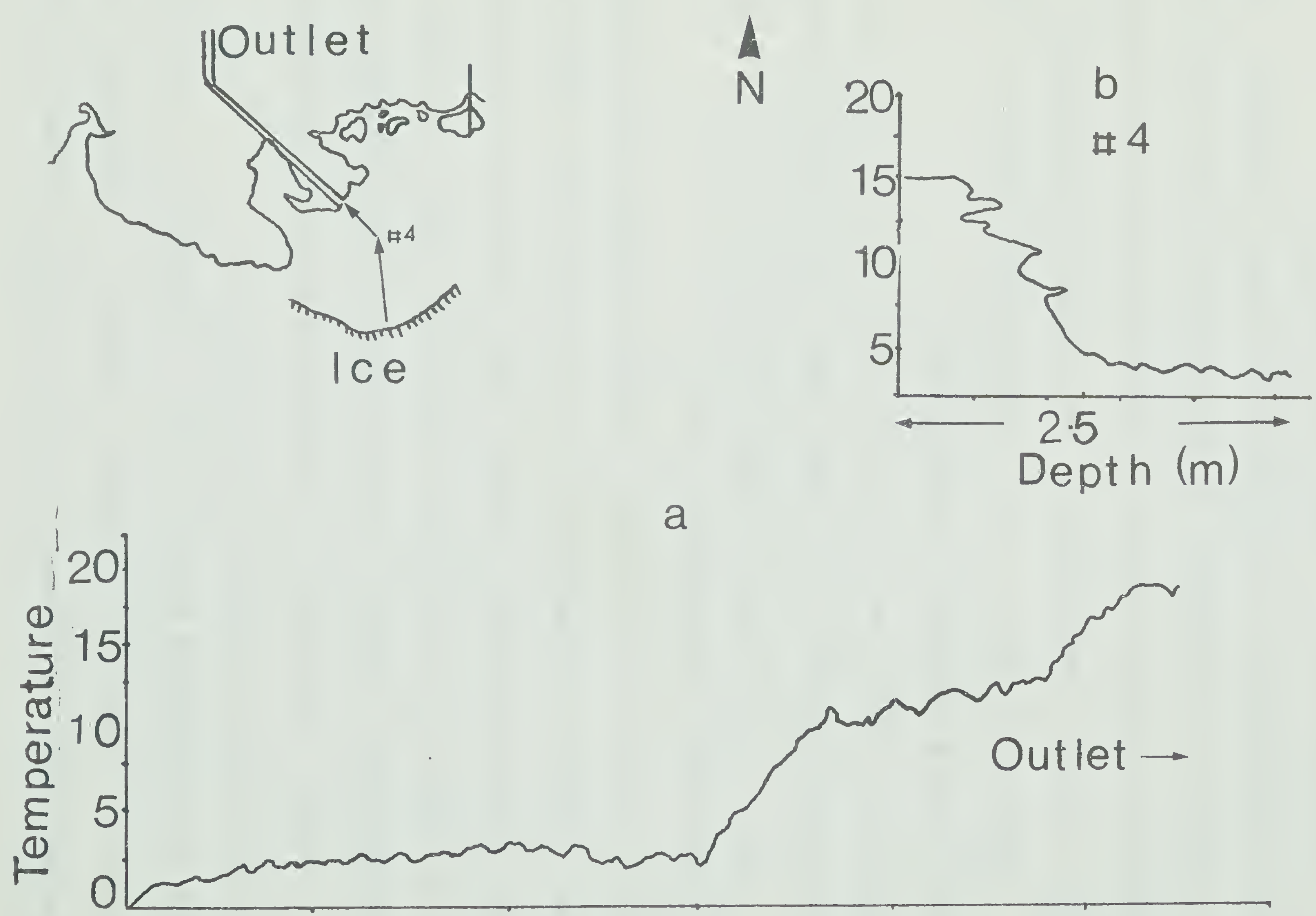
The highest surface temperature (20.4 C.) occurred during a warm, calm period in July, 1970, in the unheated part of the lake.

2. General conditions in the heated zone. Using station 4 as a typical area in the thermally influenced region (Fig. 11) it can be seen that the vertical changes in temperature are often rapid except during very windy days when complete overturn occurs. There is often a drop of up to 10 C. in the top meter of water due to the less dense warmer water floating upon the cooler denser lake water. This phenomenon produces a lens-shaped plume of hot water on top of the colder water. This type of density and current induced effect was also described by Clark (1969) for an area on the Connecticut River near a nuclear power plant effluent.

A typical vertical profile (Fig. 12) shows the extent of the heated water at station 4. A rapid increase in temperature occurs from 0 C. at the edge of the ice to 20 C. at the mouth of the outlet canal. There is a rapid decrease in temperature with increasing depth and this produces a thermocline which varies in depth depending upon the wind speed and direction, currents, and heat output. Data on wind speed are found in Table 1 and the figures are included because of the importance of wind in distributing the plume of heated effluent water after it leaves

Fig. 12. *a*. Surface temperature (C.) profile from edge of ice to mouth of outlet canal, Feb. 19, 1969.

b. Vertical temperature (C.) profile at station 4, March 8, 1969.


Outlet
#4
Ice
N
b
4
20
15
10
5
2·5
Depth (m)
a
Temperature
20
15
10
5
0
Outlet →

the outlet canal. In general, it may be stated that only the upper meter or so is affected by the great increase in temperature and lower depths in the affected zone are only raised by 1 - 2 C. On very windy days complete mixing of water will occur.

To get a better idea of the behavior and extent of influence of the heated water a series of vertical and horizontal profiles were made at various times during the study period (Figs. 13 - 20). It can be seen from these figures that the closer one gets to the outlet canal the more rapidly the temperatures of the surface meter change and the plume of hot water can be seen to increase gradually until finally no cold water can be distinguished (Fig. 16).

Figure 20 shows that, in summer, some heated water circulates around Point Alison returning to the inlet canal. This phenomenon also occurs in winter (see later) and wind is at all times very important in influencing the distribution of warmed water.

Infra-red imagery of the lake was taken on August 17, 1969 (Plates 7 and 8), and temperature was recorded simultaneously. From the graph and lake image (Plate 7) it can be readily seen that the heated water extends into Kapasiwin Bay and also around Point Alison (covering an area approximating to the area of open water in winter). Plate 8 shows the heated area in a north-south direction.

3. Winter conditions in the unheated part of the lake. Ice first appears on the lake in early November (Table 5, Fig. 21). This ice gradually increased in thickness until the maximum ice thickness was 71.9 cm. (March 26, 1969). Considering that the mean depth of the lake is only 5.6 m. approximately 12.2% of the lake is frozen by late winter (about 12.9% if there was no open water).

Fig. 13. Vertical temperature (C.) profile near outlet canal, July 5, 1968, along two transects, *a* and *b*, measured in meters in the directions indicated by arrows on map. Depth scale is same for *a* and *b*. Abscissae represent distance (in meters) from start of transects *a* and *b*.

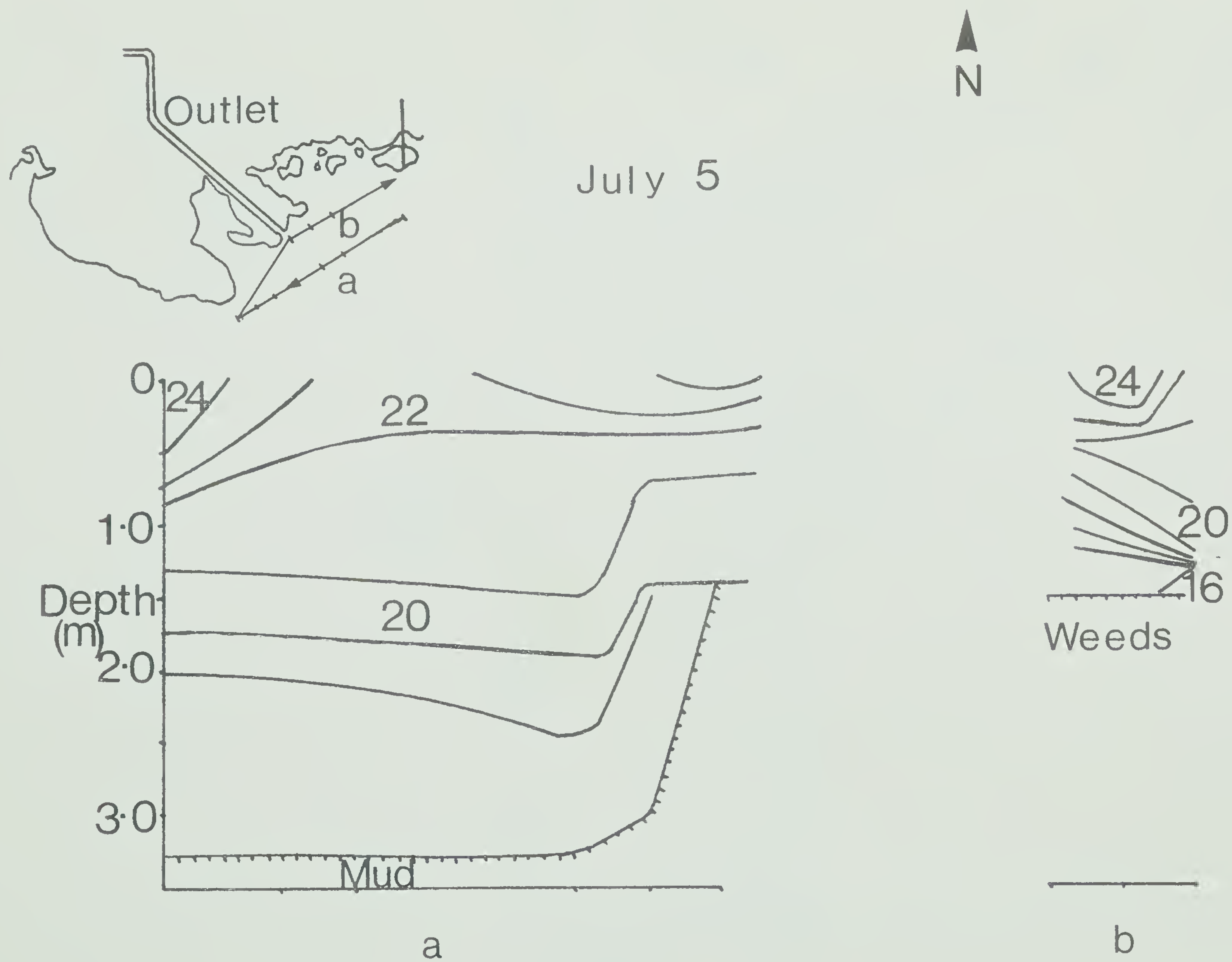

Outlet
July 5
N
b
a
0
24
22
1·0
Depth
(m)
20
2·0
3·0
Mud
24
20
16
Weeds
a
b

Fig. 14. Vertical temperature (C.) profile near Point Alison and outlet canal, July 19, 1968. Abscissa represents distance (in meters) from start of transect in direction indicated by arrow on map.

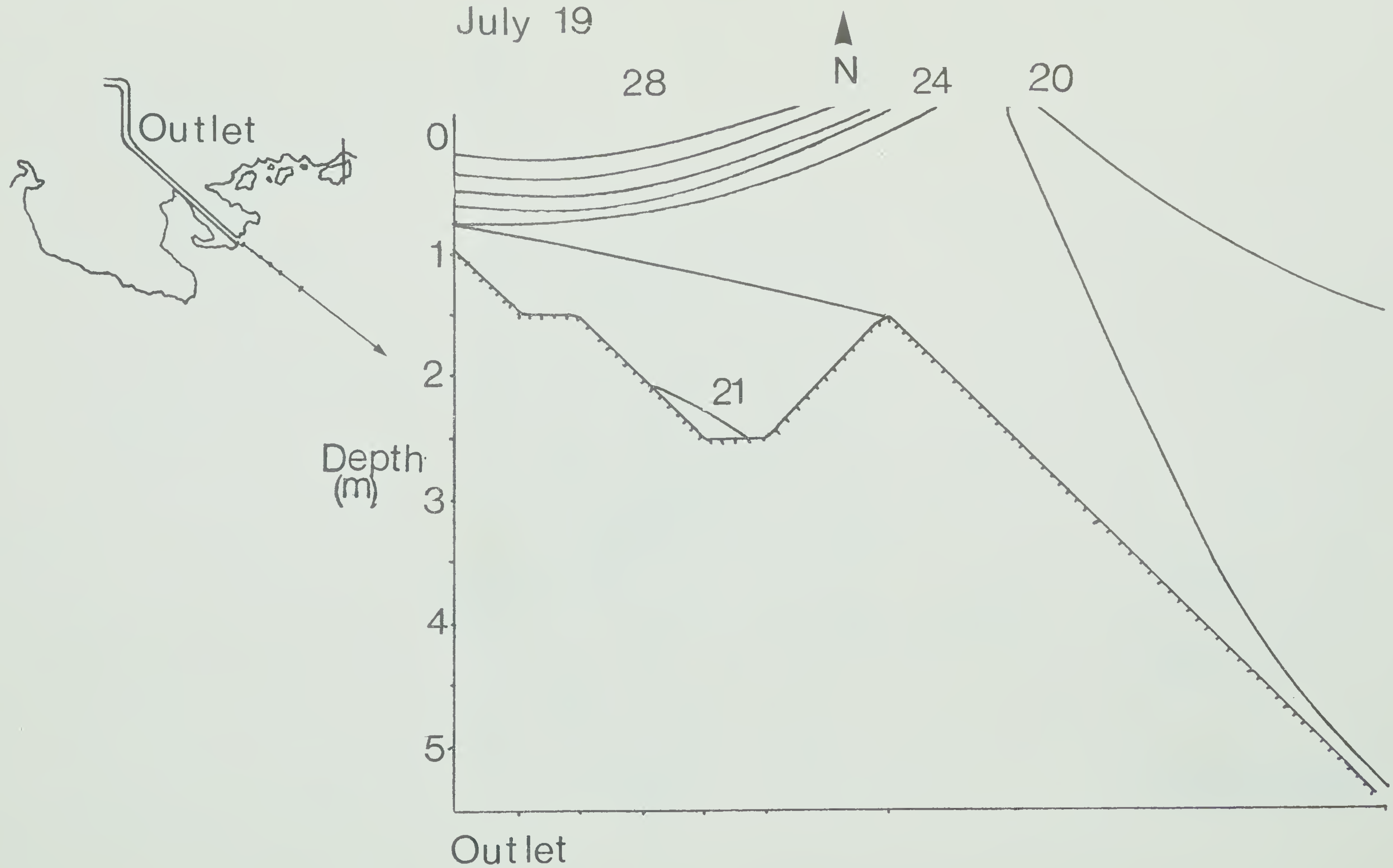
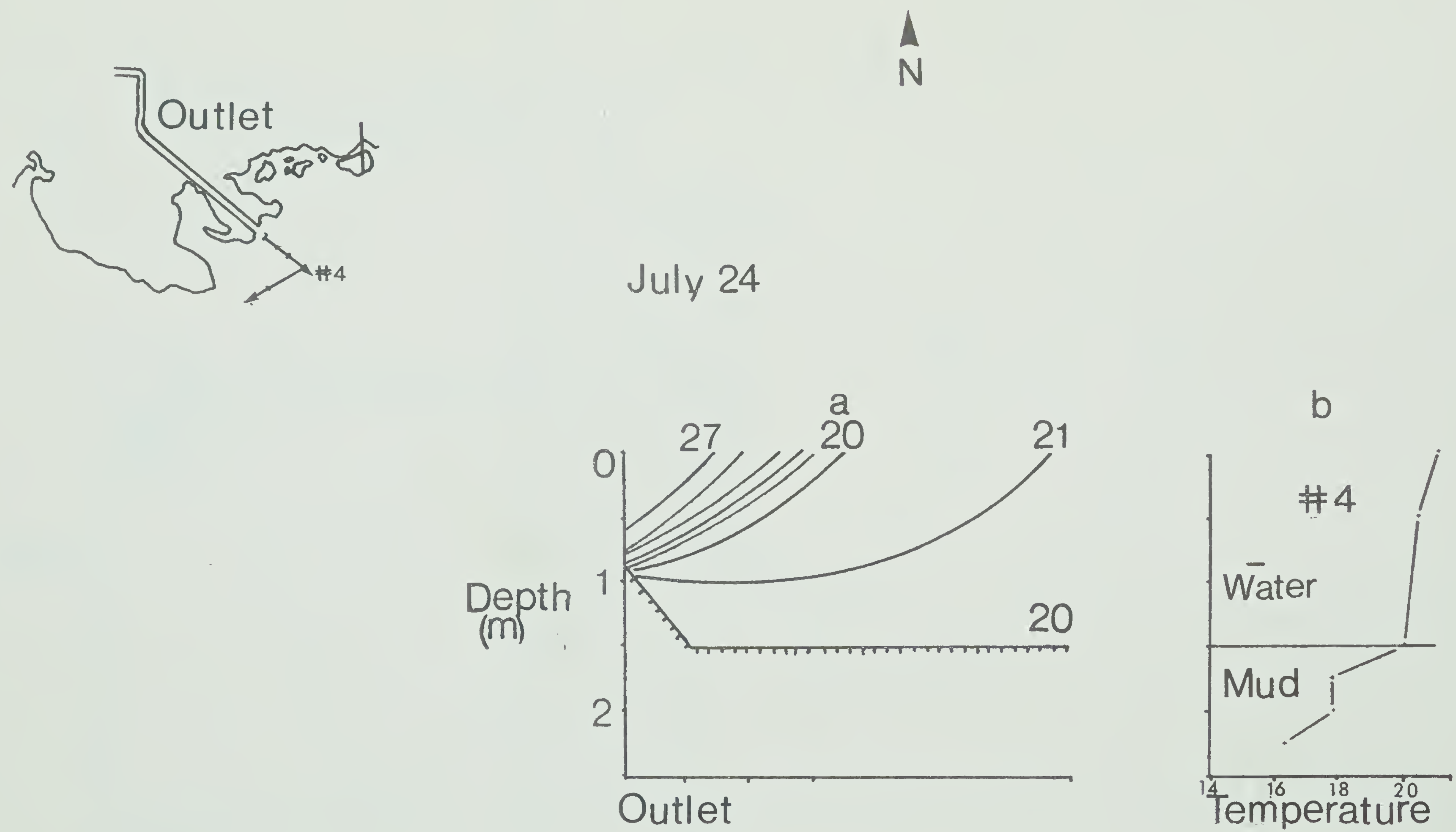

July 19
28
N
24
20
Outlet
0
1
2
21
Depth
(m)
3
4
5
Outlet

Fig. 15. *a*. Vertical temperature (C.) profile near Point Alison and outlet canal, July 24, 1968, along a linked transect with an angular break as indicated on map. Abscissa represents distance (in meters) along linked transect. Serrated line represents bottom mud.

b. Vertical temperature (C.) profile at station 4. Ordinate has same depth scale as a.



N
Outlet
#4
July 24
a
27
20
21
20
Depth (m)
0
1
2
Outlet
b
#4
Water
Mud
14
16
18
20
Temperature

Fig. 16. Vertical temperature (C.) profile from outlet canal to Moonlight Bay, Aug. 12, 1968, along linked transects with angular breaks as indicated on map. Abscissa represents distance (in meters) along linked transects. Serrated line represents bottom mud.

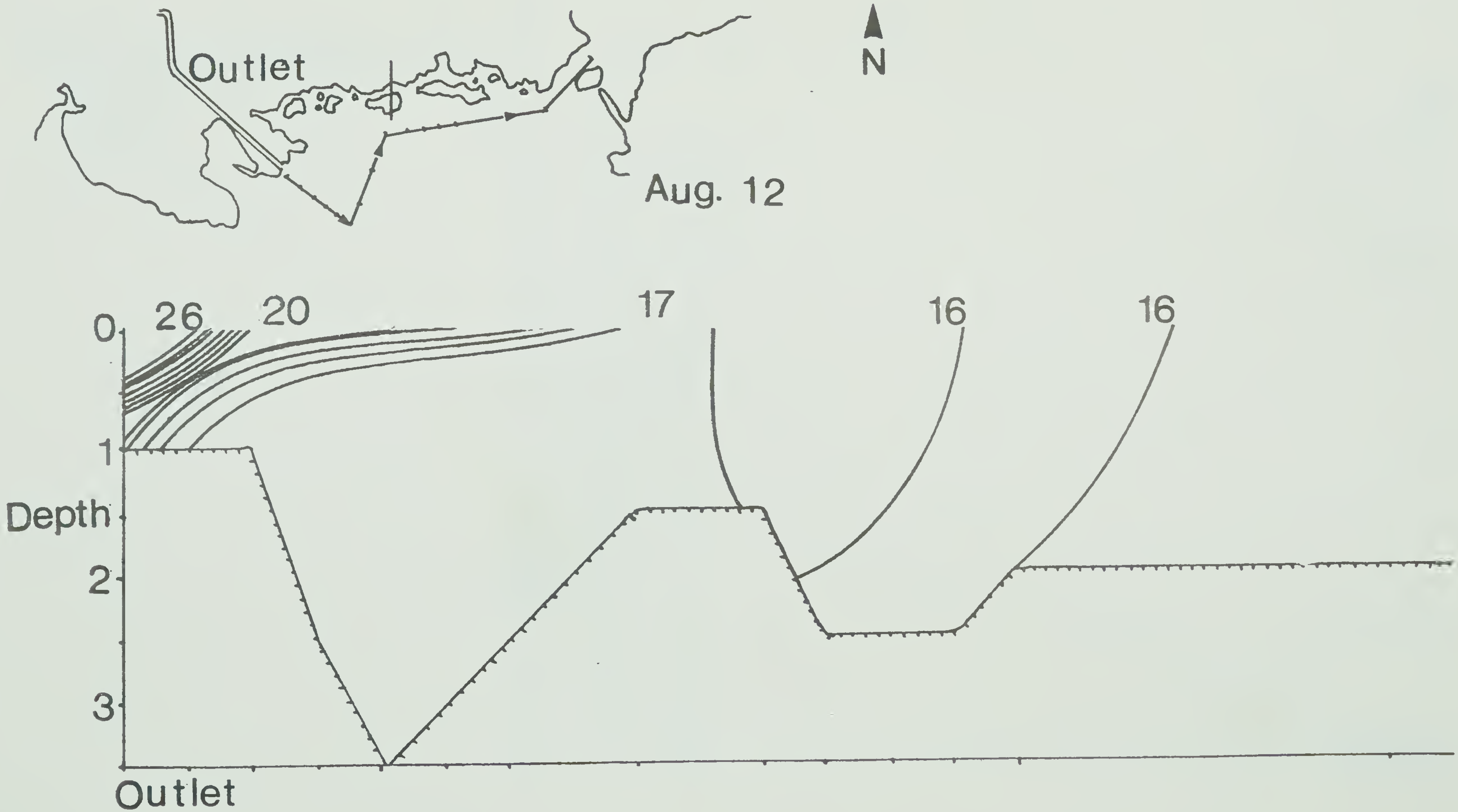

Outlet
N
Aug. 12
0
1
Depth
2
3
26
20
17
16
16
Outlet

Fig. 17. Vertical temperature (C.) profile from south-east shore of Kapasiwin Bay to outlet canal, Aug. 15, 1968. Abscissa represents distance (in meters) along linked transects. Serrated line represents bottom mud.

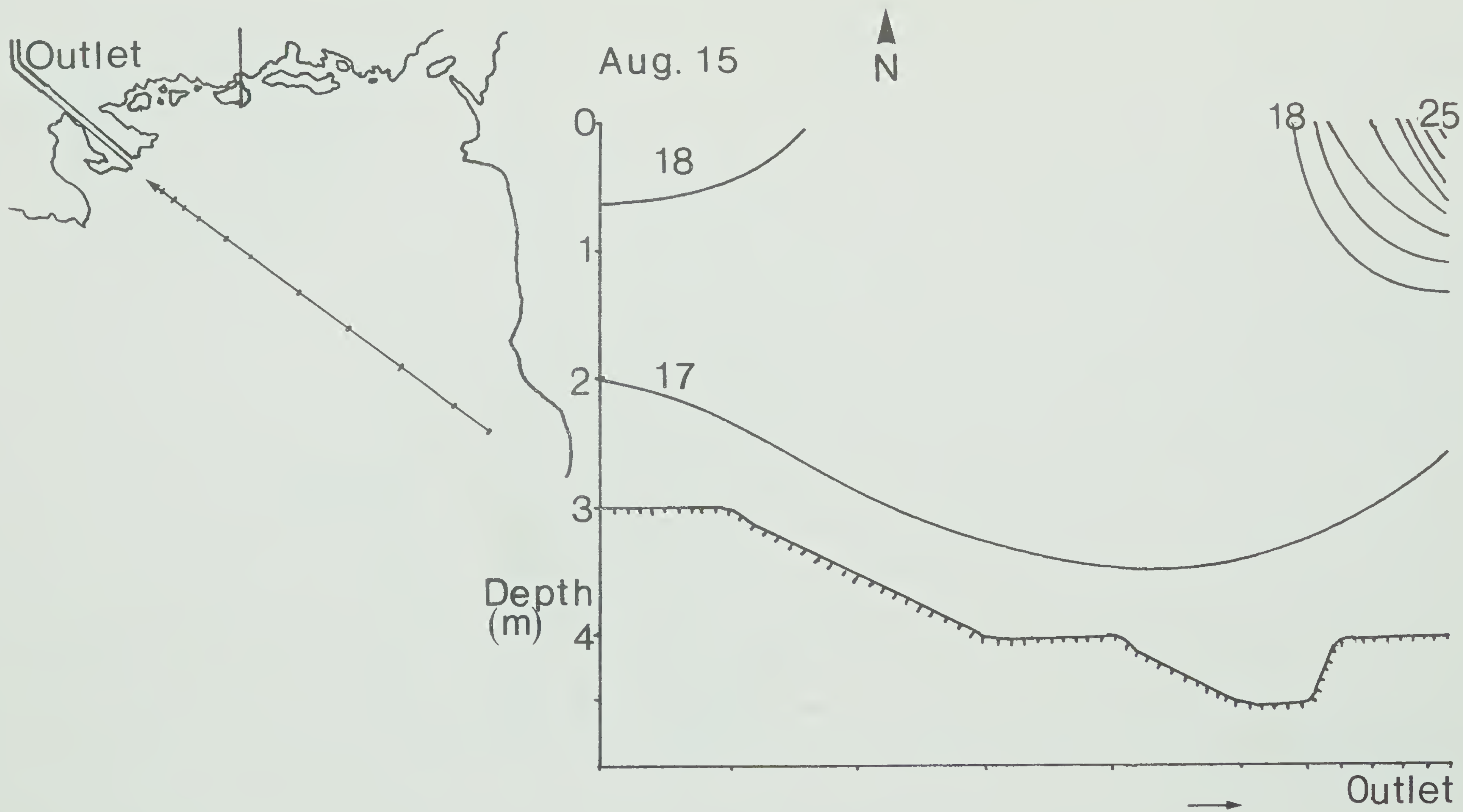
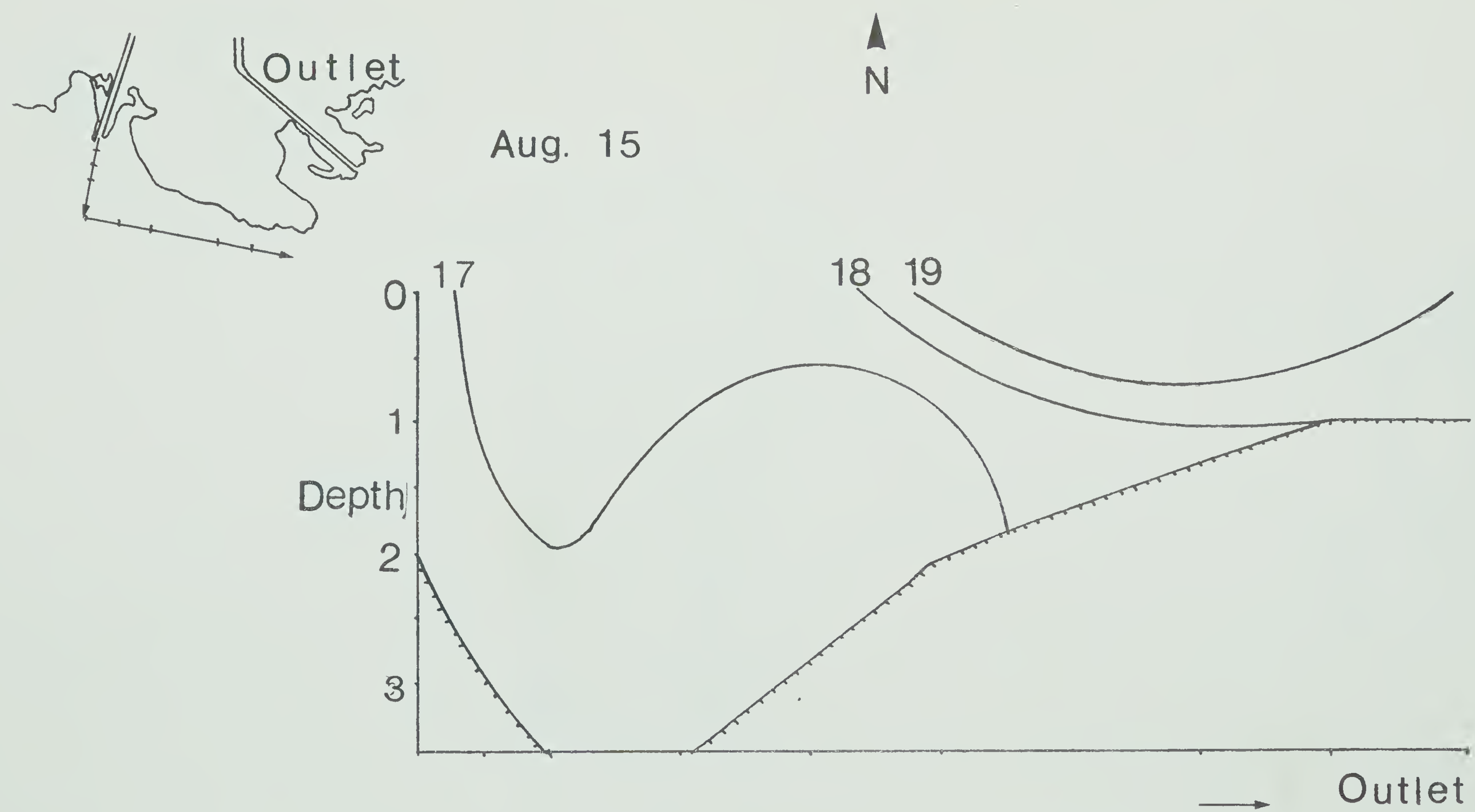
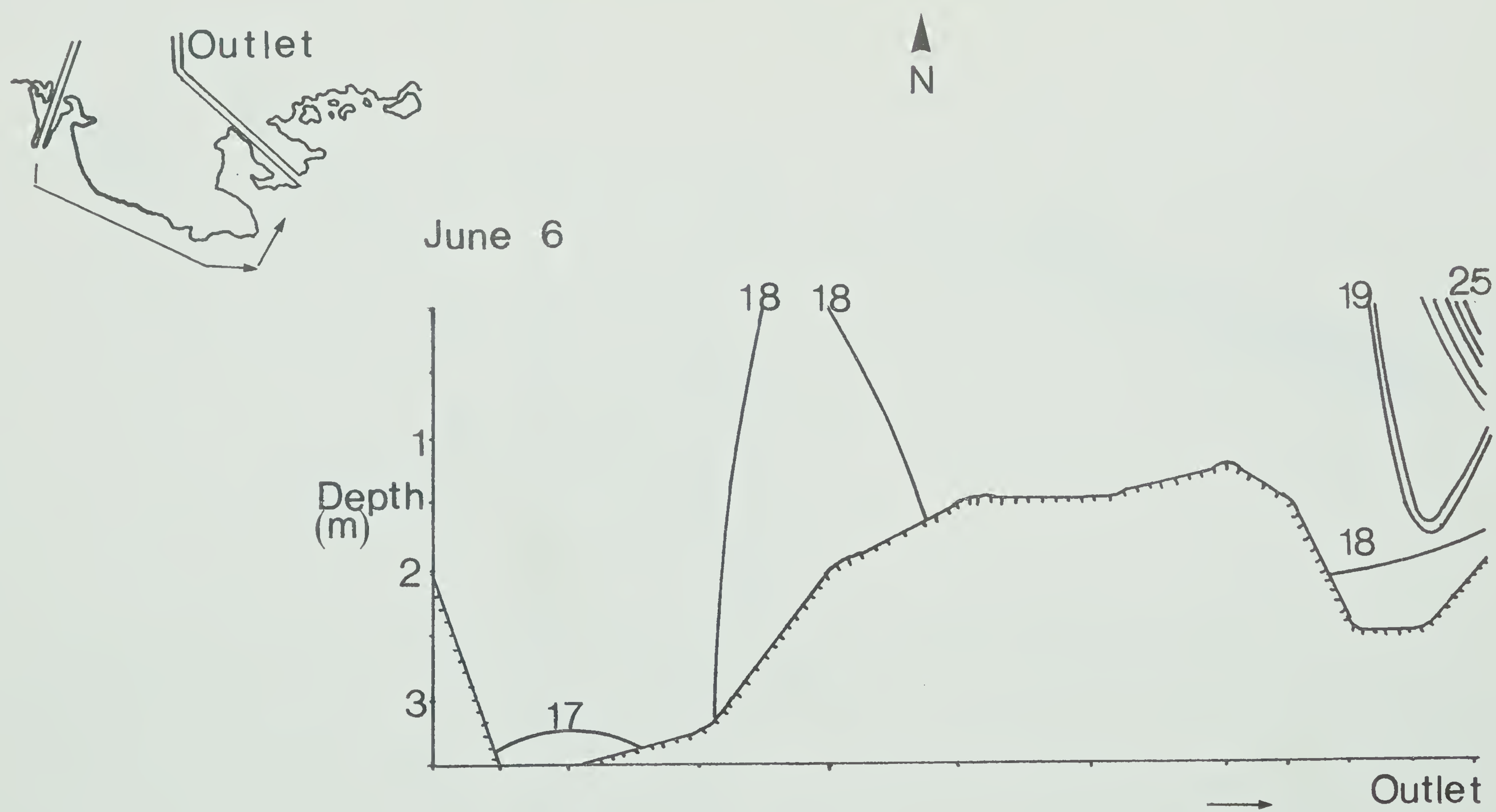

Outlet
Aug. 15
N
0
1
2
3
4
Depth
(m)
18
17
18
25
Outlet

Fig. 18. Vertical temperature (C.) profile from Point Alison to inlet canal, Aug. 15, 1968, along a linked transect with an angular break as indicated on map. Abscissa represents distance (in meters) along linked transects. Serrated line represents bottom mud.



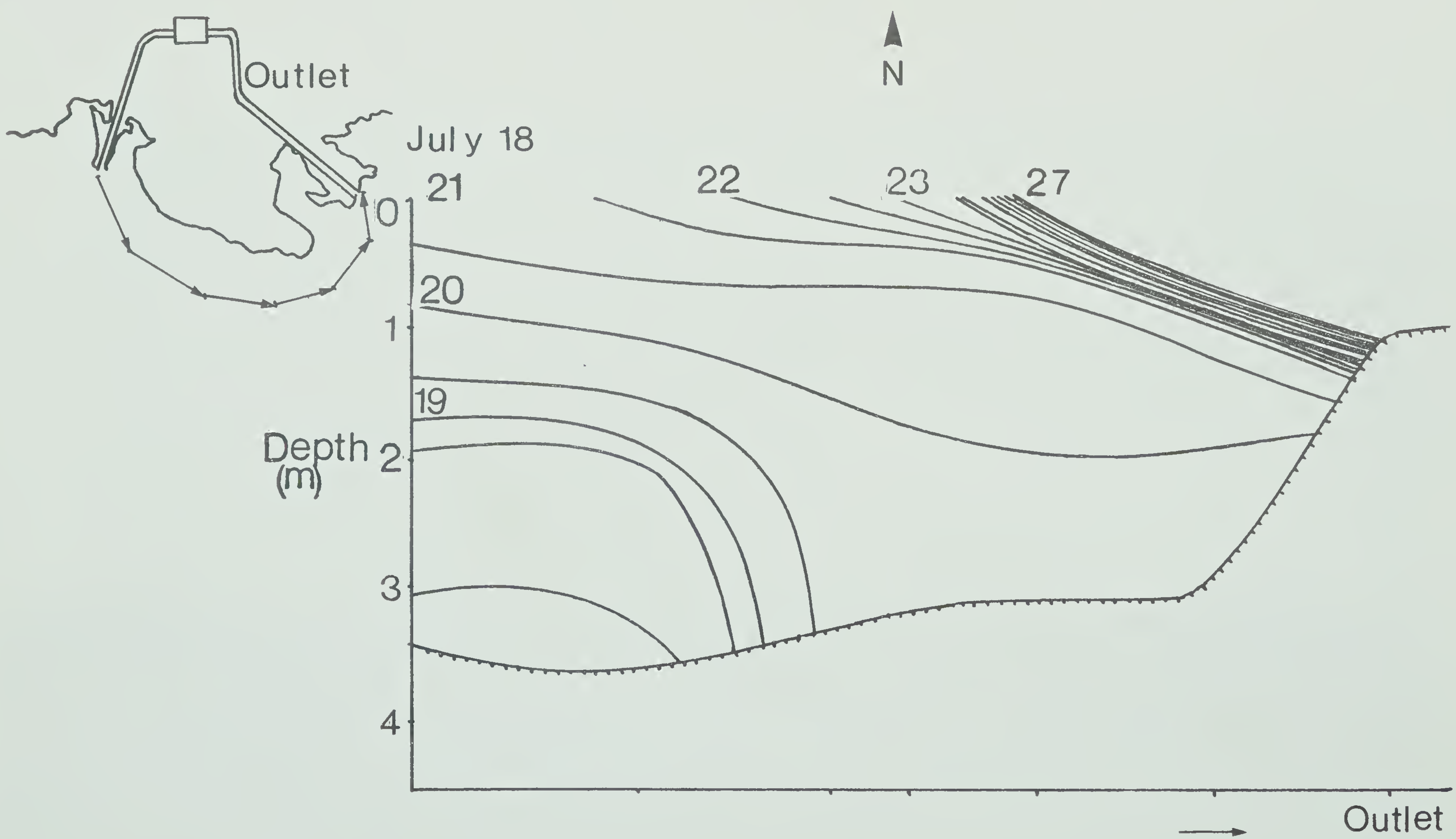
Outlet
Aug. 15
N
17
18
19
0
1
Depth
2
3
Outlet

Fig. 19. Vertical temperature (C.) profile from inlet canal to mouth of inlet canal to Point Alison, June 6, 1969, along linked transects with angular breaks as indicated on map. Abscissa represents distance (in meters) along linked transects. Serrated line represents bottom mud.



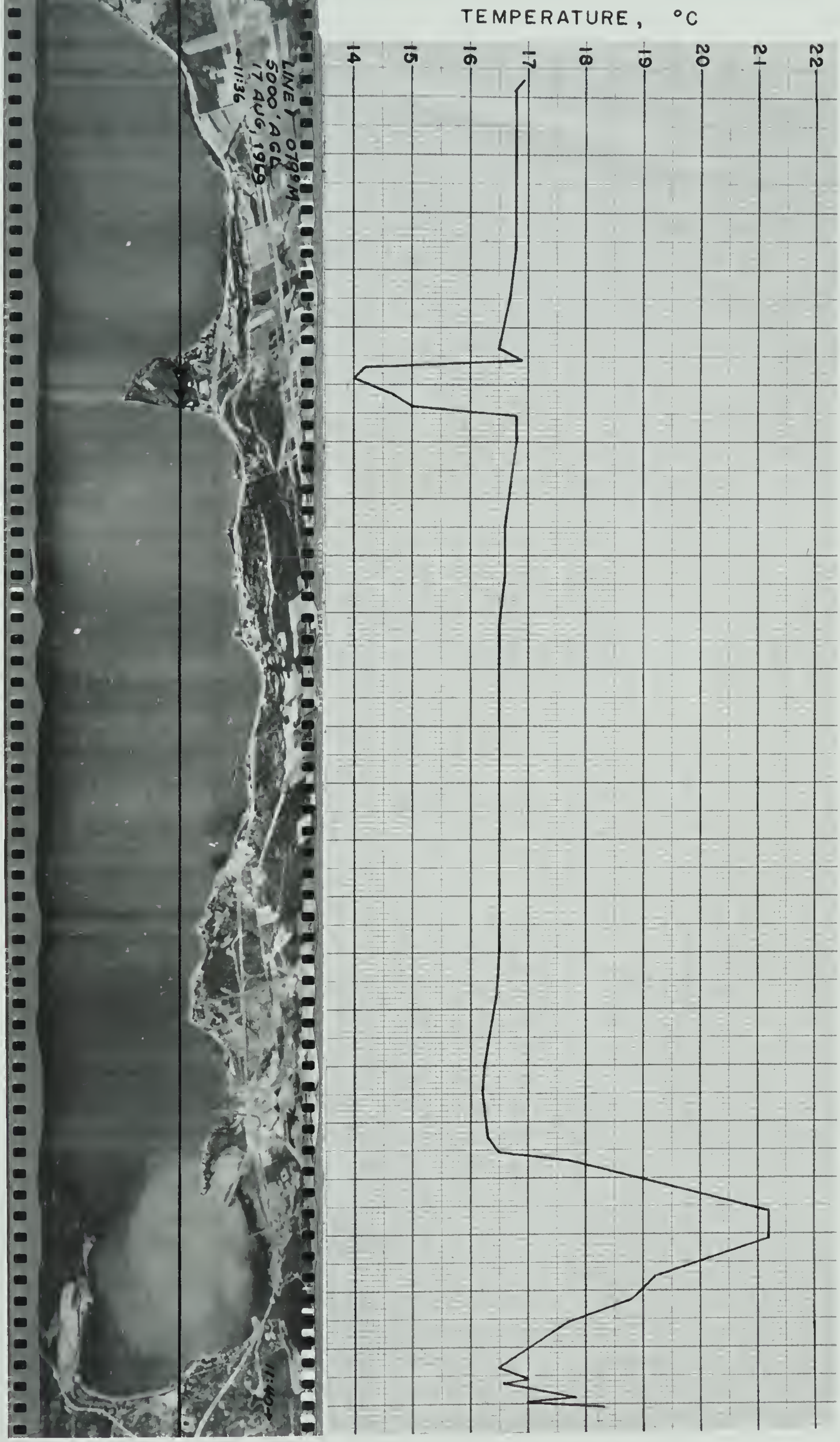
Outlet
N
June 6
Depth (m)
1
2
3
18
18
17
19
25
18
Outlet

Fig. 20. Vertical temperature (C.) profile from inlet canal to outlet canal, July 18, 1969, along linked transects with angular breaks as indicated on map. Abscissa represents distance (in meters) along linked transects. Serrated line represents bottom mud.



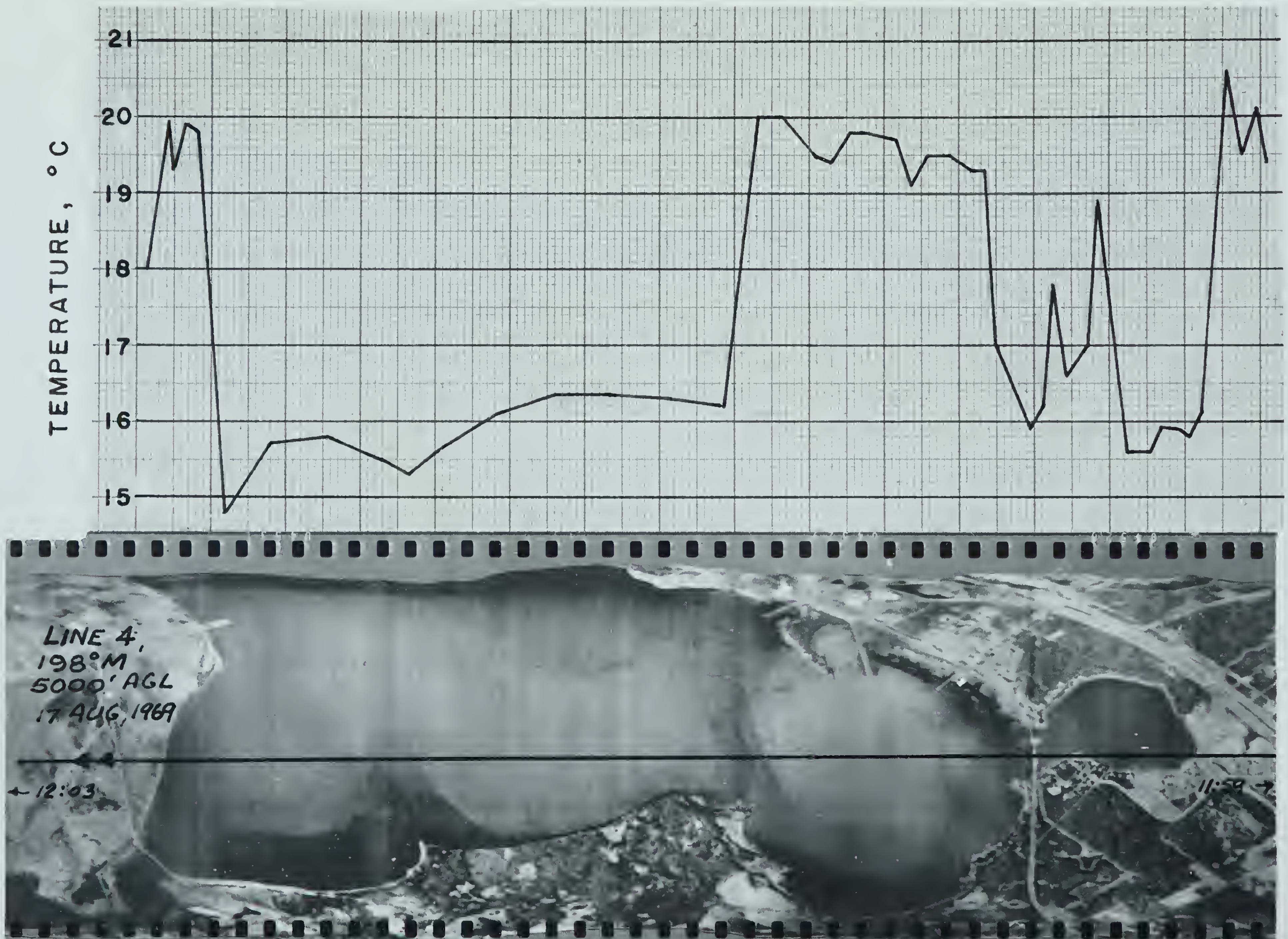
Outlet
N
July 18
21
22
23
27
20
19
0
1
Depth 2
(m)
3
4
Outlet

Plate 7. Infra-red image of the northern part of Lake Wabamun showing the extent of the heated effluent at the east end of the lake (warmer areas lighter colour). A surface temperature profile shows the increased temperature in the heated zone, Aug. 17, 1969.



TEMPERATURE, °C
14
15
16
17
18
19
20
21
22
LINE Y 079°M
5000' AGL
17 AUG, 1969
11:36
11:40

Plate 8. Infra-red image of east end of Lake Wabamun through the heated effluent (warmer areas lighter colour), on a north-south transect. Instrument sensitivity was increased during flight from mouth of Kapasiwin Bay south to Goosequill Bay. This results in light shade on this portion of the picture despite a lower temperature. A surface temperature profile shows the increase in temperature in the heated zone, Aug. 17, 1969. This transect was flown 20 minutes later than the west-east transect shown on Plate 7.



TEMPERATURE, °C
21
20
19
18
17
16
15
LINE 4,
198°M
5000' AGL
17 AUG, 1969
← 12:03
11:59 →

Fig. 21. Snow and ice measurements during winters of 1968-1969 and 1969-1970.

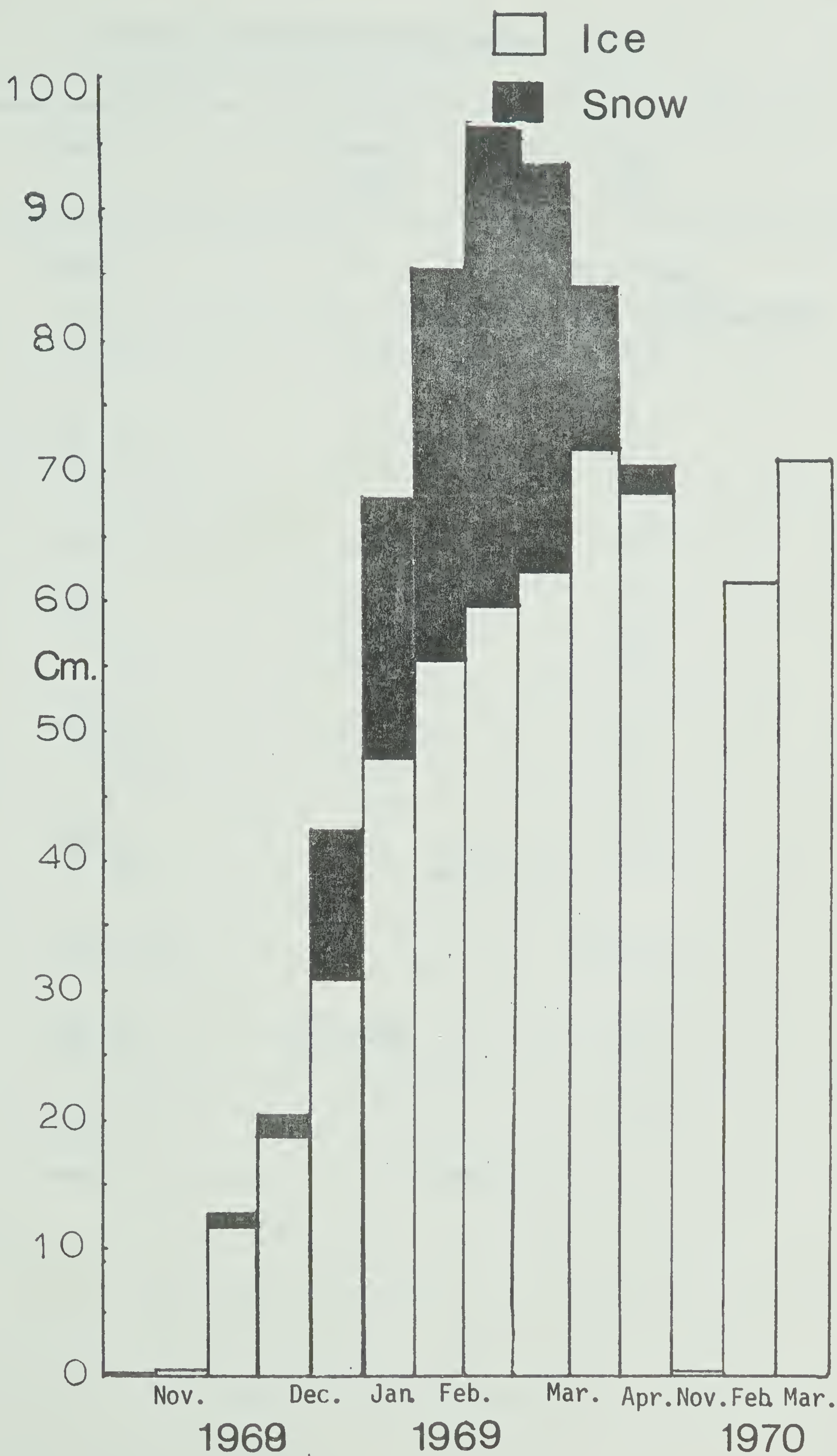

Ice
Snow
100
90
80
70
60
Cm.
50
40
30
20
10
0
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
Nov.
Feb.
Mar.
1968
1969
1970

Table 5. Snow-ice measurements, 1968-70

Year	Date	Snow (cm.)	Ice (cm.)
1968	Nov. 2	--	First seen
	" 11	--	Thin (not measured)
	" 22	1.0	11.6
	Dec. 6	1.5	18.8
	" 19	11.5	31.0
1969	Jan. 17	20.0	48.0
	Feb. 5	30.0	55.5
	" 19	36.5	59.7
	Mar. 8	31.0	62.4
	" 26	12.5	71.9
	Apr. 9	2.0	68.5
	" 24	Break-up	
	Early Nov.		First seen
1970	Feb. 21	Not known	61.5
	Mar. 27	" "	71.0
	May 1	Break-up	

4. Winter conditions in the heated zone. A variable area remains ice-free each winter due to the influence of heated water (Fig. 22). Surface temperature, as mentioned, decreases rapidly from the outlet canal to the edge of the ice-free area (Fig. 12). Usually the boundary of the open water zone has a surface temperature close to 0 C. (Fig. 12, Plate 9). Next to this area there is a zone of thin ice (Fig. 22) gradually becoming thicker as the distance away from the thermally influenced zone increases.

The shape and extent of this open water area depends upon the influence of wind and currents. Only a small portion of the north end of Kapasiwin Bay was ice free during January 1969. During January 1969, an extremely cold month, the open water area was confined to the north end of Kapasiwin Bay (Fig. 22*a*). In January 1969 and March 1969 the prevailing winds were from the north-west (Fig. 22*a*,*b*). In March 1969 the heated water pushed further south into Kapasiwin Bay (Fig. 22*b*). On both these occasions the area around Point Alison remained ice-free, apparently due to the influence of winds and currents. It appears that some of the warmed water from the outlet canal circulates around the point and returns to the inlet canal. This situation would indicate that some of the same water is being used again and again by the power plant.

Prevailing west winds (Table 1) during December, 1969, kept the open water to the north end of Kapasiwin Bay (Fig. 22*c*). At times during the winter of 1970 (Fig. 22*d*) the area around Point Alison had a thin ice cover. It would appear that less warmed water circulated around Point Alison because of the prevailing west wind during February 1970. It is more common (as in the winter of 1969) to have prevailing north-westerly winds at this time of the year.

Fig. 22. Map of east end of Lake Wabamun showing changes in shape and extent of open water, prevailing winds in the area, Jan. 1969 to Feb. 1970.

a. Jan. 1969 (Monthly mean temperature - 15.7°F)

b. Mar. 1969 (Monthly mean temperature + 22.5°F)

c. Dec. 1969 (Monthly mean temperature + 20.0°F)

d. Feb. 1970 (Monthly mean temperature + 21.5°F)

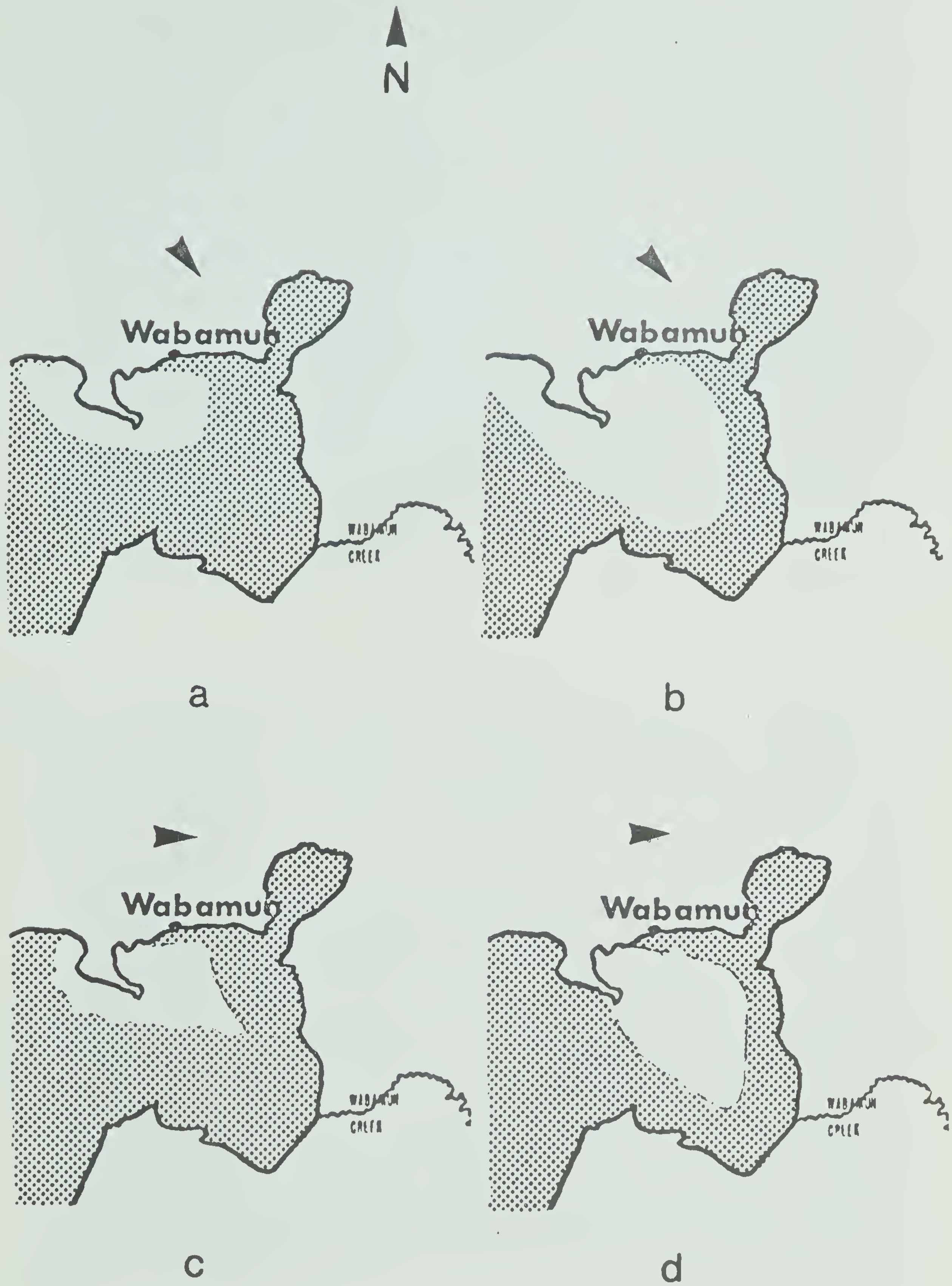

N
Wabamun
a
Wabamun
b
Wabamun
c
Wabamun
d

Plate 9. Boundary of open water zone and ice. The ice is thin near the edge of this area and gradually increases in thickness with increasing distance from the heated water.

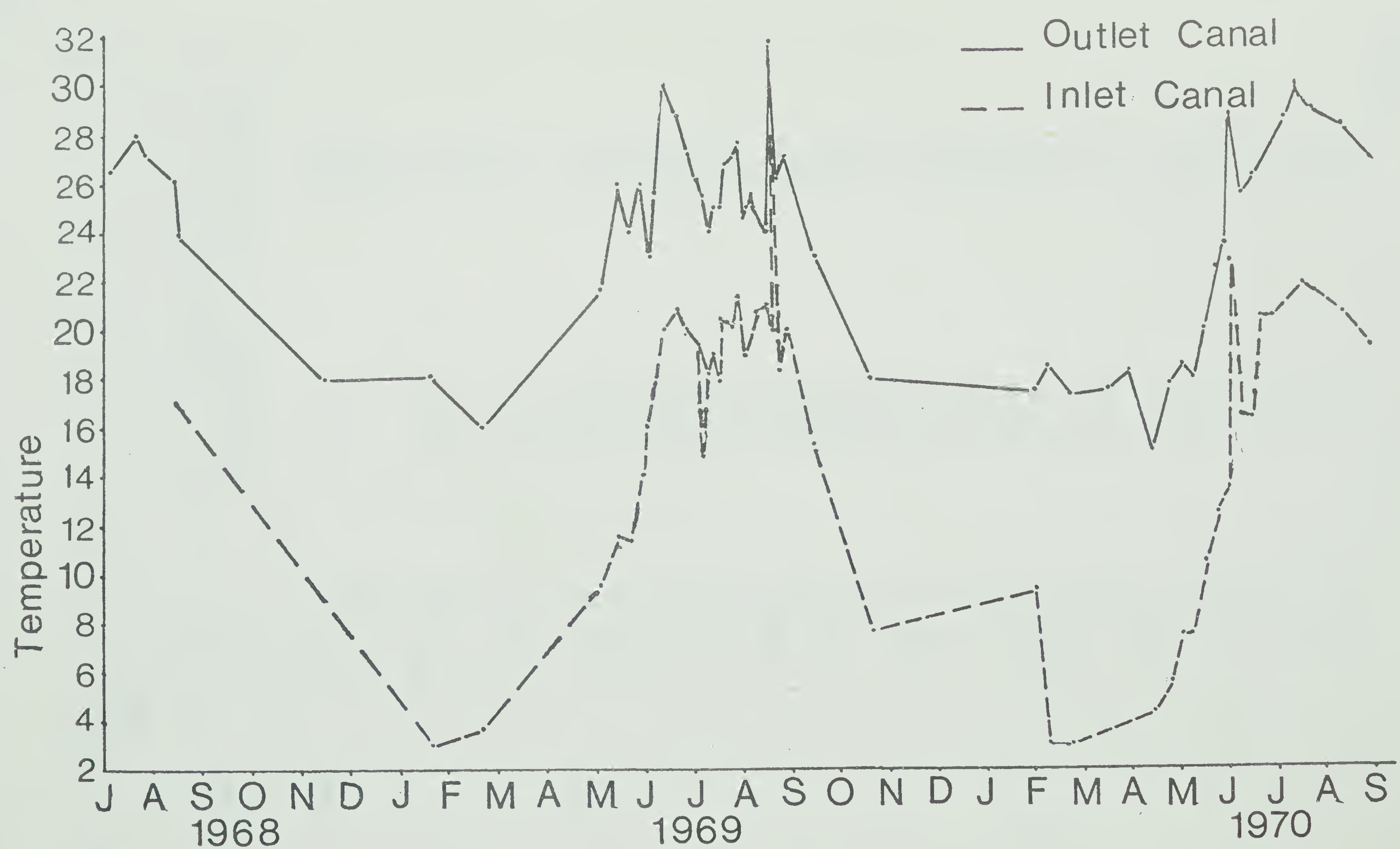
Plate 10. Mouth of outlet canal looking north towards Wabamun Power Plant.

5. <u>General conditions in the inlet and outlet canals</u>. It has been shown in the preceding sections that some of the cooled warm water is used again and again because some of the heated water passes around Point Alison and flows back into the inlet canal. Figure 23 shows that there is a close correlation in variations between the canal temperatures at all times of the year although there is a difference in mean temperature of 8.73 C. (Table 6). Maximum temperature recorded in the outlet canal was 31.8 C. (Aug. 15, 1969).

During August 1969 a continuous recording thermometer was placed in the outlet canal (Fig. 24, Plate 10) to measure daily temperature changes. Some of the time temperatures were in excess of 30.0 C. which was outside the range of the instrument. Fluctuations up to 7.0 C. occurred on several days and these great changes are apparently attributed to a change in output of power from the plant. These sudden temperature changes could produce more stress upon organisms than continuously elevated temperatures and need further investigation.

Temperature measurements made during 1970 are mentioned in a later section dealing with the effects of temperature upon certain members of the zooplankton.

Fig. 23. Temperature changes (C.) in inlet and outlet canals, July 1968 to Aug. 1970.



Outlet Canal
Inlet Canal
Temperature
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
J A S O N D J F M A M J J A S O N D J F M A M J J A S
1968
1969
1970

Table 6. Temperature measurements in inlet and outlet canals, 1968 - 1970.

Year	Date	Temperature °C.	
		Inlet Canal	Outlet Canal
1968	July 5	-	26.5
	" 19	-	28.0
	" 24	-	27.3
	Aug. 12		26.1
	" 15	17.0	-
	" 19	-	23.9
	Nov. 22	-	18.0
1969	Jan. 17	3.0	18.2
	Feb. 19	3.6	16.0
	May 2	9.5	21.6
	" 13	11.5	25.5
	" 20	11.3	24.0
	" 27	14.0	26.0
	June 2	16.0	23.0
	" 6	17.8	25.7
	" 10	20.0	30.0
	" 17	20.8	28.8
	" 24	20.0	27.2
	July 2	19.4	26.2
	" 4	15.8	25.5
	" 8	18.2	24.0
	" 11	19.0	25.0
	" 15	17.9	25.0
	" 18	20.5	26.8
	" 22	20.1	27.0
	" 25	21.3	27.7
	" 30	18.9	24.6
	Aug. 1	20.7	25.1
	" 7	21.0	25.5
	" 12	20.0	24.0
	" 15	27.9*	31.8*
	" 21	18.3	26.2
	" 26	20.0	27.2
	Sept. 13	15.3	23.0
	Oct. 19	7.7	18.0

(Cont'd)

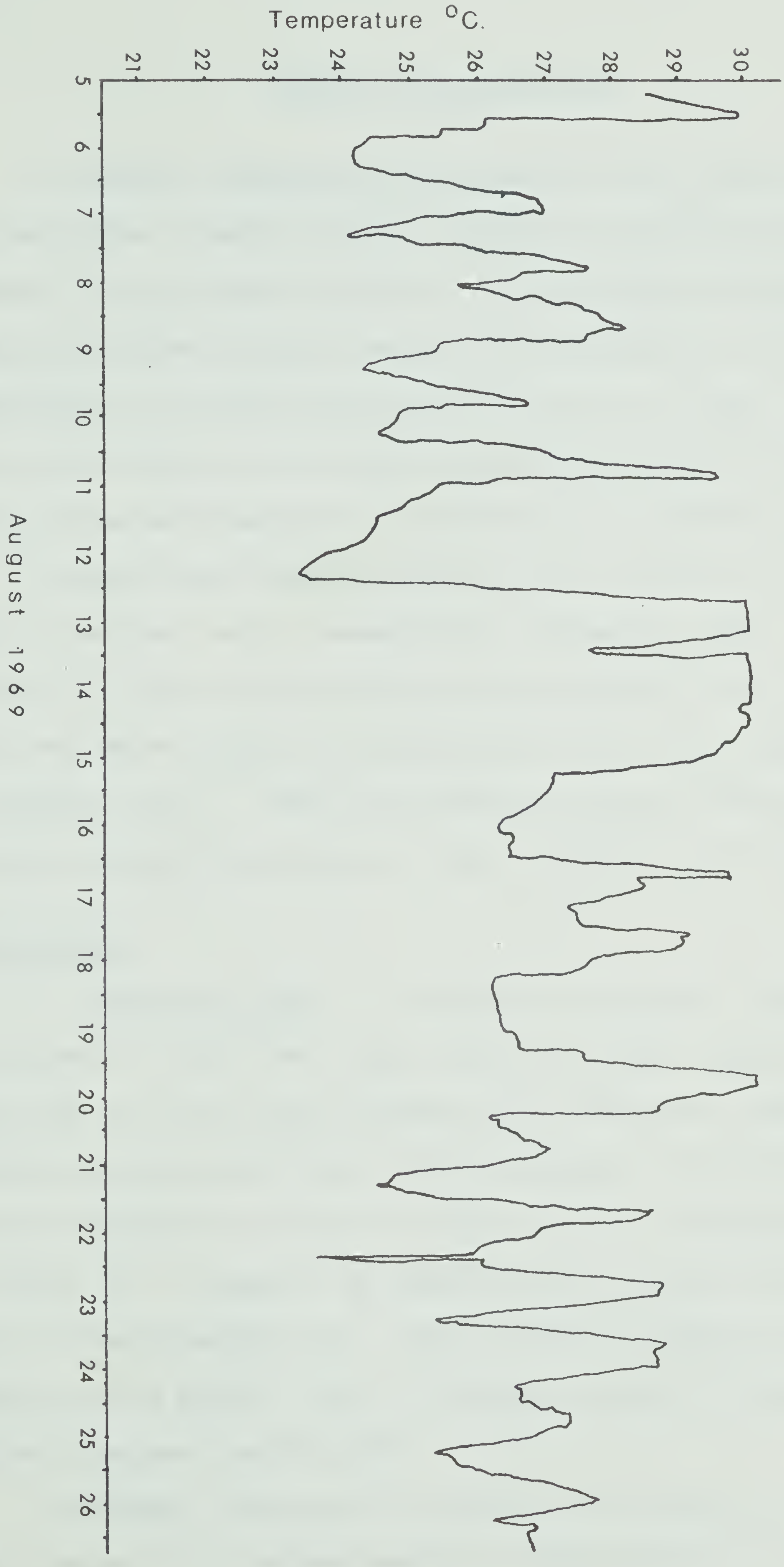
Table 6 (Cont'd)

Year	Date	Temperature °C.	
		Inlet Canal	Outlet Canal
1970	Jan. 31	9.3	17.5
	Feb. 7	3.0	18.5
	" 21	3.0	17.3
	Mar. 15	-	17.5
	" 27	-	18.3
	Apr. 11	4.3	15.0
	" 24	5.5	17.8
	May 1	7.5	18.5
	" 6	7.5	18.0
	" 14	10.5	20.0
	" 21	12.5	22.4
	" 29	13.5	23.5
	June 3	22.9	28.8
	" 12	16.6	25.6
	" 19	16.4	26.3
	July 3	20.6	28.7
	" 10	-	30.0
	" 17	21.8	29.4
	" 24	21.5	29.0
	Aug. 10	20.7	28.4
	" 27	19.3	27.1

Inlet $\bar{X}$ = 15.38 C.
Outlet $\bar{X}$ = 24.11 C.

Mean Diff. - 8.73 C.

Fig. 24. Daily temperature changes (C.) in outlet canal, Aug. 1969.


Temperature °C.
21
22
23
24
25
26
27
28
29
30
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
August 1969

CHEMICAL CHARACTERISTICS

The chemical composition of any natural body of water is determined by a multitude of complex factors, including geological and meteorological features. In any closed lake basin, such as Wabamun, precipitation and spring runoff form the major sources of the nutrients in the water. Evaporation will increase the ionic concentration of such a lake during the ice-free season, and a natural equilibrium between the processes of precipitation and evaporation will determine its chemical composition.

The major water chemistry analyses were carried out at stations 4 and 13 (stations 1 and 2, respectively, of Wheelock, 1969; Fig. 2). In addition to these stations analyses were performed on water from the inlet and outlet canals, at the Building Products (B.P.) effluent, and at Sundance (Fig. 3). Many of the chemical analyses carried out would not seem relevant here and these results are found in the Appendix.

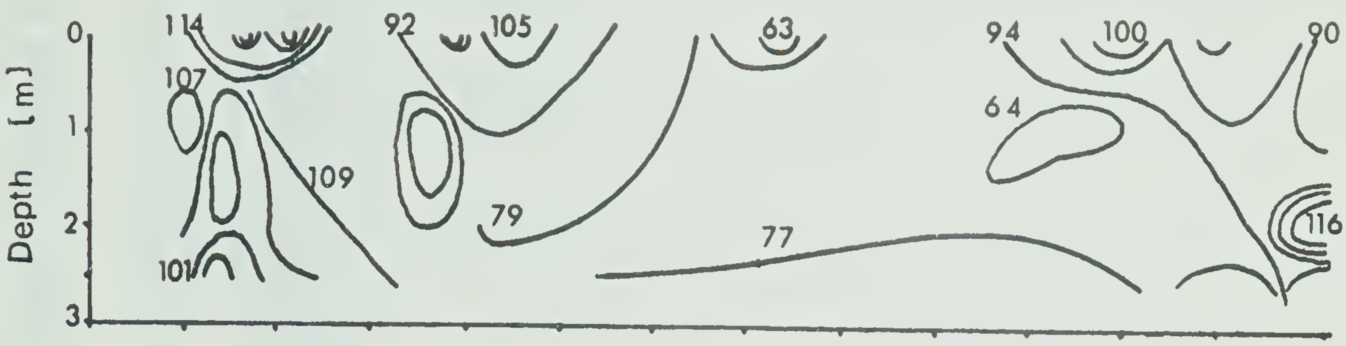
Surface Water

1. Dissolved oxygen. A limnologist can probably learn more about the nature of a lake from a large series of seasonal oxygen determinations than from all other kinds of chemical data (Hutchinson, 1957). Vertical dissolved oxygen profiles were taken fortnightly or more frequently at one meter intervals at station 4, and at two meter intervals at station 13 (Table 7). In general, the oxygen curves at station 4 had a tendency to be of the orthograde type. This is probably because the water is shallow at this station. Most of the oxygen curves at station 13 were of the clinograde type (Fig. 25).

The highest saturations were found to be in the top two meters at both stations with a maximum reading of 132% saturation recorded at

Fig. 25. Seasonal changes of % oxygen saturation at stations 4 and 13, 1968-1969.

Station 4



Station 13

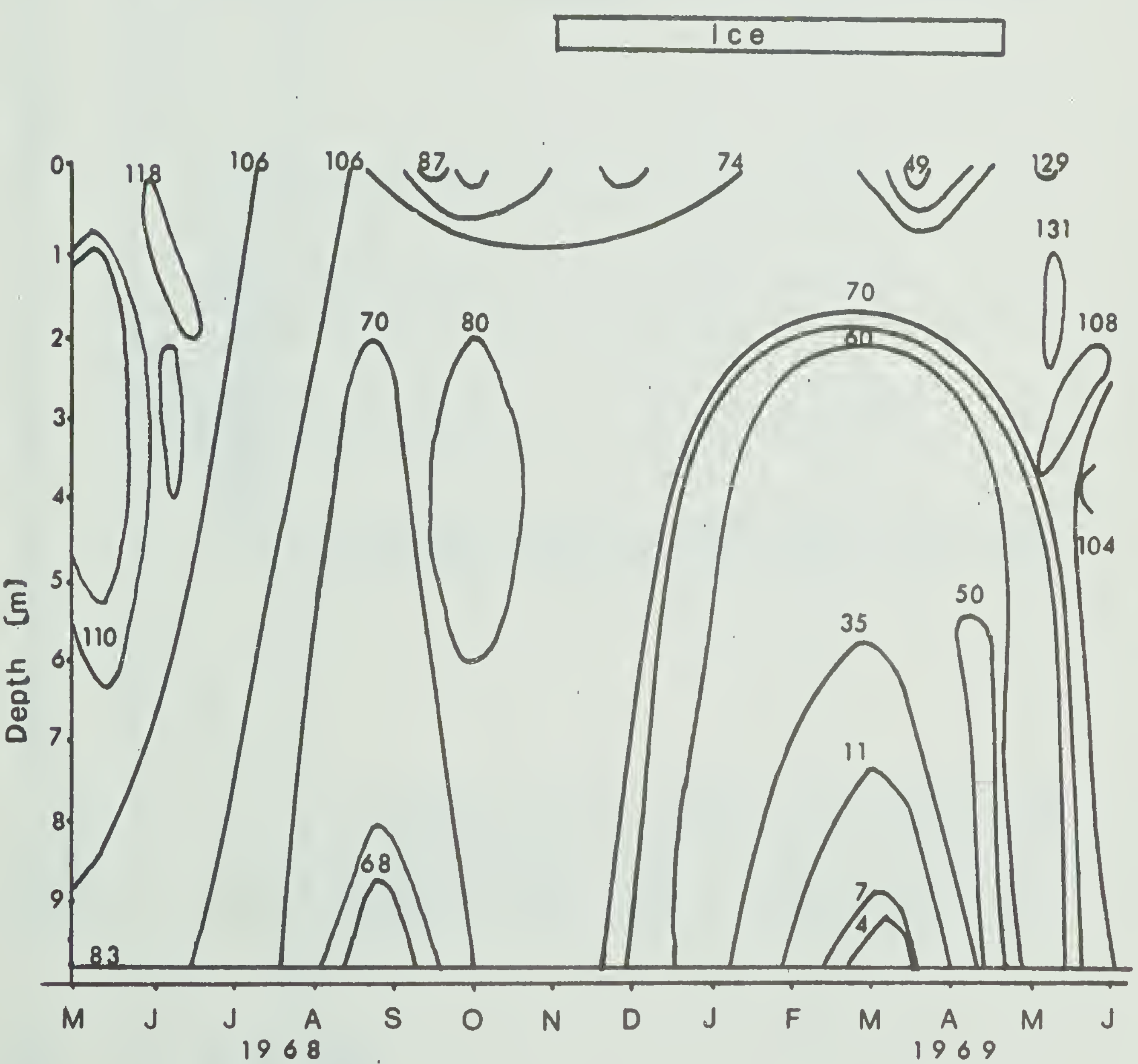


Table 7. Vertical dissolved oxygen concentrations at stations 4 and 13, 1968-1969 (expressed as per cent saturation.

		Station 4				Station 13					
Year	Date	Depth in meters				Depth in meters					
		0	1.0	2.0	2.5	0	2.0	4.0	6.0	8.0	9.75
1968	May 30	114	107	104	101	112	111	111	110	107	83
	June 6	100	90	90	58	118	116	110	106	99	43
	" 18	92	88	87	86	87	87	88	83	90	56
	" 26	122	106	104	88	117	118	106	94	108	106
	July 3	132	---	---	---	122	---	---	---	---	---
	" 7	107	---	---	---	114	---	---	---	---	---
	" 16	109	---	---	---	101	---	---	---	---	---
	Aug. 6	85	---	---	---	74	---	---	---	---	---
	" 13	111	---	---	---	84	---	---	---	---	---
	" 21	114	119	116	109	99	---	---	---	---	---
	" 27	83	---	---	---	111	---	---	---	---	---
	Sept. 4	104	92	79	---	73	70	---	---	69	68
	" 27	105	---	---	---	87	---	---	---	---	---
	Oct. 12	92	89	82	77	89	80	81	80	85	73
	Nov. 11*	108	---	---	---	82	---	---	---	---	---
	" 22*	73	---	---	---	---	---	---	---	---	---
	Dec. 6*	63	---	---	---	100	---	---	---	---	---
	" 19*	73	---	---	---	96	---	---	---	---	---

(Cont'd)

Table 7 (Cont'd)

		Station 4				Station 13					
		Depth in meters				Depth in meters					
Year	Date	0	1.0	2.0	2.5	0	2.0	4.0	6.0	8.0	9.75
1969	Jan. 17*	---	---	---	---	74	---	---	---	---	---
	Feb. 19*	----	---	---	---	96	63	---	15	---	7
	Mar. 8*	99	64	77	---	68	60	---	35	11	4
	" 26*	100	---	---	---	49	---	26	---	---	4
	Apr. 9*	98	94	---	87	58	---	---	---	---	---
	" 28*	109	---	---	---	61	53	56	50	---	49
	May 6	111	101	96	88	104	107	---	95	70	70
	" 13	129	---	119	---	129	131	109	90	108	76
	" 20	122	---	120	---	---	---	---	---	---	---
	" 27	90	88	116	105	116	107	98	104	101	104

*For the period Nov. 11 - Apr. 28 there was open water at station 4 and ice cover at station 13.

station 4, on July 3, 1968. Supersaturations of this order can be attributed largely to photosynthesis.

A comparison of surface dissolved oxygen concentrations between the two stations is shown in Figure 26. The greatest differences between the two stations were noticed in winter when the concentration of oxygen began to fall markedly at station 13 because of the depletion of oxygen under the cover of snow and ice. This covering was not present in the heated area (station 4) and the concentration of oxygen was higher there because the unfrozen surface water was exposed to the air. Warm water has a smaller capacity for carrying dissolved oxygen than cooler unaffected lake water. In Lake Wabamun, water in the heated zone has its oxygen continually replenished by the currents and wind moving across station 4 from the outlet canal.

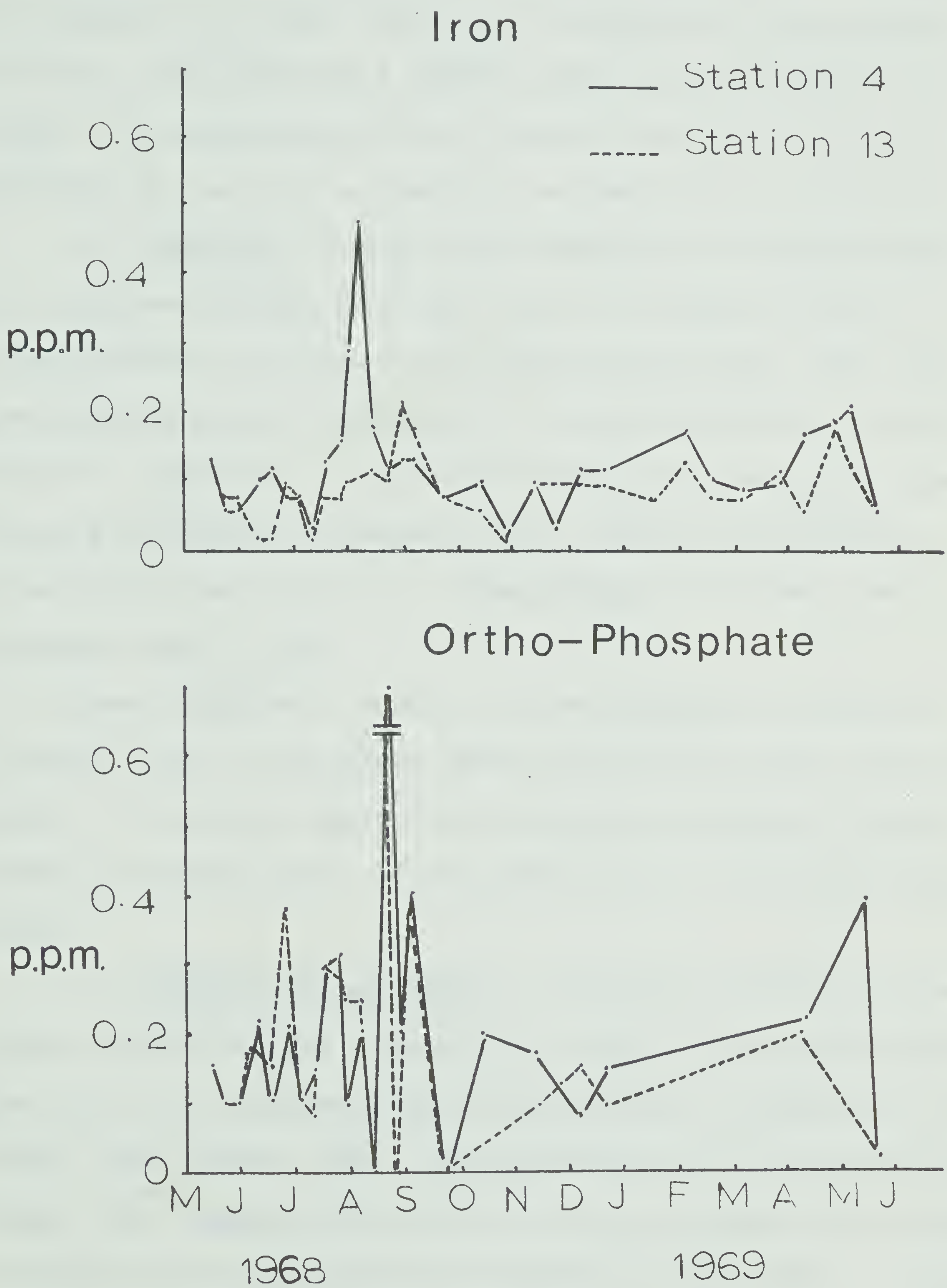
Vertical profiles of per cent oxygen saturation at the two stations (Fig. 25) show that there are great differences between the two stations, particularly during late winter just above the bottom at station 13 where almost no oxygen was present (4% saturation, March 1969). However, despite the almost complete absence of oxygen near the bottom at station 13 in February and March, no winter kill of bottom feeding lake whitefish (*Coregonus clupeaformis*) was reported from the lake. Perhaps the fish avoided this area.

2. Iron. It seems that in well-oxygenated lakes the iron compounds likely to be present are suspended ferric hydroxide and a non-reducible complex or series of complexes (Hutchinson, 1957). Harvey (1937) presented some experimental results which suggest that both of these forms may be assimilated by diatoms and possibly by other planktonic organisms.

Fig. 26. Surface seasonal changes of % oxygen saturation at stations 4 and 13, 1968-1969.


Station 4
Station 13
Ice Cover
% Saturation
140
120
100
80
60
40
0
M J J A S O N D J F M A M J
1968
1969

Fig. 27. Seasonal changes of iron and ortho-phosphate (p.p.m.) at stations 4 and 13, 1968-1969. (Cf. Table 7, Wheelock, 1969)


Iron
Station 4
Station 13
0.6
0.4
p.p.m.
0.2
0
Ortho-Phosphate
0.6
0.4
p.p.m.
0.2
0
M J J A S O N D J F M A M J
1968
1969

The lowest concentration of iron in Lake Wabamun is found in late spring followed by a rapid increase during the early summer (Fig. 27; Appendix II). After a decrease in concentration in late summer and early autumn there was a gradual increase during late fall and winter. The mean concentration of iron was found to be 0.11 p.p.m. This type of iron cycle is similar to one described by Ivlev (1937).

3. Phosphorus. Chalupa (1959) found that the maximum values for phosphates occurred after heavy rains. The highest values of ortho-phosphate were found in Lake Wabamun during August, 1968, and precipitation may have contributed to the amount present in the water (Fig. 27; Appendix II). Part of the increase may have resulted from decaying macrophytes (Hutchinson, 1957). The mean ortho-phosphate concentration was 0.22 p.p.m. Ortho-phosphate is the most common phosphate found in lakes.

Under conditions of summer or autumn stagnation, it is known (Chalupa, 1959) that phosphates diffuse from mud into water above the bottom. It has been suggested that the amount of phosphate released depends, at least in part, on the amount of iron in the water (Einsele, 1941).

4. Biochemical Oxygen Demand. The five-day Biochemical Oxygen Demand (B.O.D.) test was carried out on a number of occasions (Table 8). The B.O.D. is an arbitrary measure of the bacterial consumption of oxygen (Hynes, 1966; Ruttner, 1963). The Royal Commission on Sewage Disposal (Hynes, 1966) suggested that a B.O.D. of 4 p.p.m. should not be exceeded in Britain. One reading of 4.9 was recorded in Lake Wabamun. In general, the warm water of the outlet canal had a higher B.O.D. than that of the cooler inlet canal.

Table 8. Five-day Biochemical Oxygen Demand test (p.p.m.) results, summer, 1969

Date	Location	Depth	B.O.D.	Temperature °C.
July 11	Sundance	Om.	2.7	17.5
		1.0	4.9	17.4
	Outlet Canal	0	2.5	25.0
		1.0	3.3	25.0
	Inlet Canal	0	1.9	19.1
		1.0	1.8	19.0
July 25	Sundance	1.0	1.0	13.8
	Station 4	0	2.1	25.5
		1.0	2.1	21.0
	Outlet Canal	0	1.2	27.7
		1.0	0.9	27.7
	Inlet Canal	0	1.2	21.3
		1.0	1.3	21.3
Aug. 7	Sundance	0	2.3	21.5
	Station 13	0	1.0	21.3
		1.0	1.7	20.7
	Outlet Canal	1.0	2.5	25.5
	Inlet Canal	0	2.0	21.0
		1.0	1.3	21.0

5. Hydrogen sulphide. The hydrogen sulphide test was carried out on a few occasions during the late winter of 1969, just above the bottom mud at station 13, but despite the low oxygen concentration there no hydrogen sulphide was ever recorded.

Surface Ice

Comparison of some chemical characteristics of ice with under-ice lake water. In addition to the routine chemical analyses carried out on unfrozen lake water, some ice was melted down on six different occasions at station 13 and the resulting water was chemically examined. These results are presented in Appendices IV and V.

Outlet and Inlet Canals and Building Products (B.P.) Effluent

During the summer of 1969 samples of water were analysed from the outlet and inlet canals and the Building Products (B.P.) plant (Appendix VI). In most instances the means for the B.P. plant were higher than those for the outlet and inlet canals and also stations 4 and 13. The greatest exception was the mean of the B.P. effluent for copper (0.01 p.p.m.) which was very much lower than the 0.23 p.p.m. and 0.26 p.p.m. for the outlet and inlet canals, respectively. The mean for chloride (5.25 p.p.m.) was slightly lower than the means of 6.16 p.p.m. and 5.19 p.p.m. for the outlet and inlet canals, respectively. The generally higher recordings of the B.P. plant were recorded only in the immediate vicinity of the effluent and were not reflected in the values measured for the outlet canal little more than a few meters downstream as these readings compared favourably to those of the 'normal' lake water (i.e., stations 4 and 13).

Comparing the means of the results measured at the outlet and inlet canals with the values recorded at stations 4 and 13 the readings were quite similar in some of the analyses. The following exceptions had mean readings at stations 4 and 13 less than the means for the outlet and inlet canals: the total alkalinity of 196 p.p.m. (stations 4 and 13) compared to 211 p.p.m. at both the outlet and inlet canals; means of 0.20 p.p.m. (station 4) and 0.12 p.p.m. (station 13) for copper were lower than the values of 0.23 p.p.m. and 0.26 p.p.m. for the outlet and inlet canals, respectively. A few readings had mean values which were greater at stations 4 and 13 than at the outlet and inlet canals. The total dissolved solids with a mean of 352 p.p.m. were greater than the means of 323 p.p.m. and 325 p.p.m. at the outlet and inlet canals, respectively. The mean for ortho-phosphate of 0.22 p.p.m. (stations 4 and 13) was much higher than the 0.07 p.p.m. and 0.06 p.p.m. values measured at the outlet and inlet canals. The mean for silica of 3.1 p.p.m. (stations 4 and 13) was greater than the 2.07 p.p.m. and 2.04 p.p.m. of the outlet and inlet canals and sulphate which had mean values which differed greatly between the two stations (35.4 p.p.m. at station 4 and 81.3 p.p.m. at station 13) were both greater than the means of 20.0 p.p.m. and 22.0 p.p.m. at the outlet and inlet canals, respectively. The mean values for the two canals were more similar to one another than they were to the two lake stations.

These results show that the heated effluent is not altered chemically by the addition of heat. Also, the similarity of the results for the two canals is in agreement with the observation mentioned earlier that water flowing out of the power plant via the outlet canal is recirculated around Point Alison. It would seem that the funneling of water from a surrounding

area into the inlet canal and then via the power plant into the outlet canal is using much of the same water again and again.

Chemical Analysis of Bottom Sediment

Some chemical and physical characteristics of bottom sediments at stations 4 and 13, 1968-1969. Bottom mud was analysed, from stations 4 and 13, by the Provincial Soil and Feed Testing Laboratory during the period from June 1968 through May 1969 (Appendix VIII). In most instances, the concentrations of the various substances were higher at station 13 than at station 4. The substrate may be richer in concentration at station 13 because of the complete absence of weeds there and, hence, less uptake of ions. However, it should be mentioned that there is a great distance between the two stations and that it is quite possible that there would be substantial differences in the constituents of the muds of the two regions just as the soils around the lake may vary in different areas. Also, there is a relatively swift flow of water at station 4 which could wash some of the sediment away from the area.

BIOLOGICAL CHARACTERISTICS

Macrophytes

The greatest concentration of emergent vegetation is located at the shallower east end of the lake (Fig. 28). During the summer there is such an abundance of floating weeds that boating and sampling in the vicinity of the outlet canal and Kapasiwin Bay is extremely difficult. Decaying weeds are often washed up on the east shore of Kapasiwin Bay during windy weather and this causes problems for many summer residents in the region.

During the summer of 1970 vegetative mapping was carried out by Dale Allen (Botany Department) and he very kindly permitted me to use the data for late summer distribution of species presented in Figure 28.

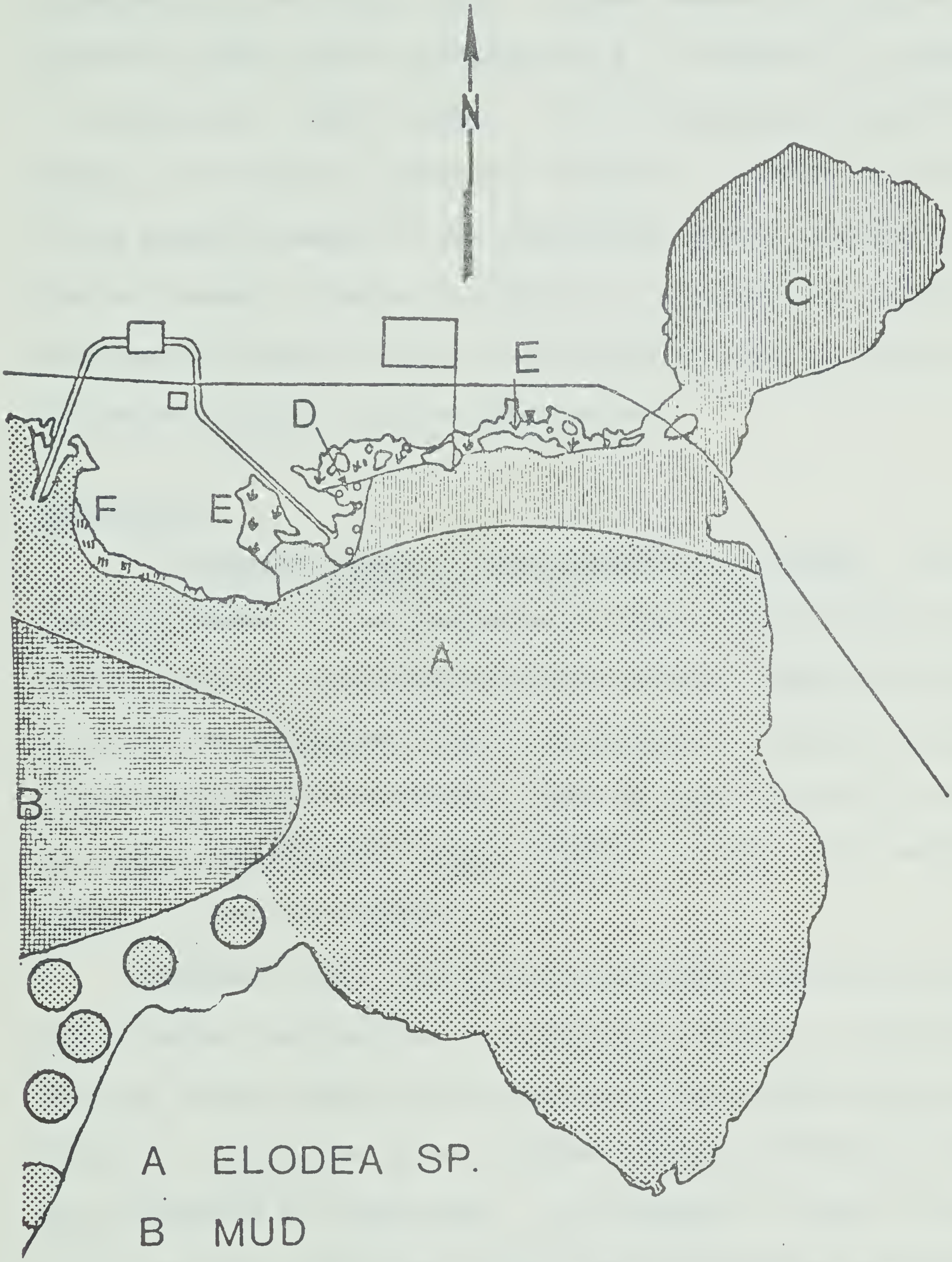
The dominant macrophyte in Kapasiwin Bay was *Elodea canadensis* (Fig. 28 A) where station 4 was located. Stations 2 and 3 were located in a mixture of *Elodea* and *Myriophyllum exalbescens* (Fig. 28 C).

Potamogeton pectinatus is found in the outlet canal and in the area immediately around its mouth (Fig. 28 D) where station 1 was located. It is a characteristic macrophyte of shallow water (Moss, 1967). Around Point Alison there was a narrow zone of *Chara* sp.

Phytoplankton

A detailed account of the phytoplankton of Lake Wabamun may be found in Wheelock's (1969) thesis. The effects of temperature on a regularly occurring member of the phytoplankton, *C. hirundinella,* were analysed. In the pump samples, *Ceratium hirundinella* first appeared on May 14 (Fig. 29), shortly after the break-up of ice (about May 1). *C. hirundinella* is a warm water species and is found in both eutrophic and

Fig. 28. Map of macrophyte vegetation of east end of Lake Wabamun, summer 1970.



A ELODEA SP.

B MUD

C MIXED - see text

D POTAMOGETON PECTINATUS

E EMERGENT VEGETATION

F CHARA SP.

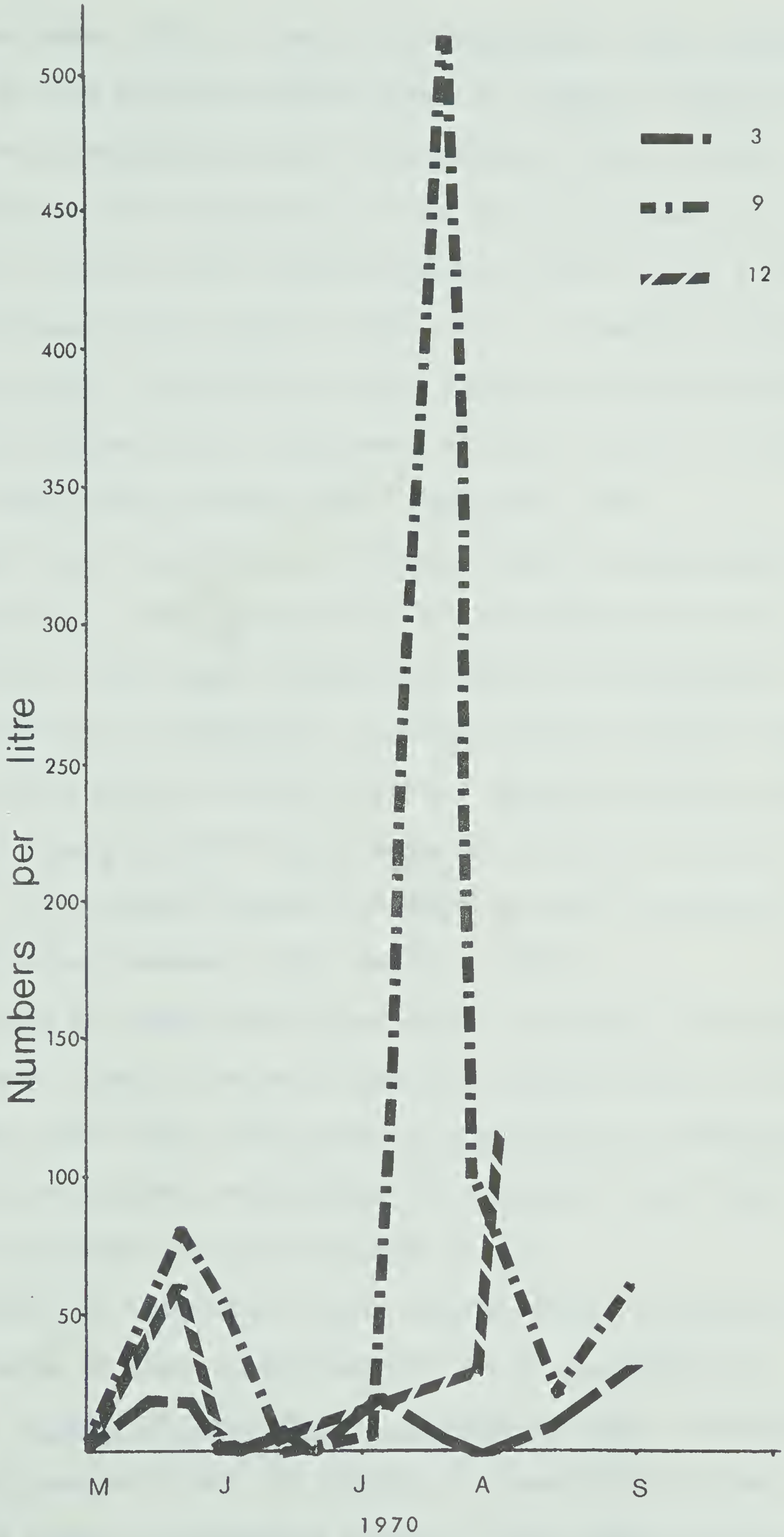
oligotrophic lakes (Höll, 1928). In Lake Wabamun this species only occurred in water above a minimum of 9.8 C. compared to a minimum of 8.3 C. in Pearsall's (1932) studies. It is interesting to note that least numbers of the species occurred at station 3, slightly more at station 12 and greatest numbers in the intermediate station 9 (Fig. 29). Greatest numbers occurred at station 9 at a temperature of 21.9 C. These results suggest that *C. hirundinella* dislikes the warmest water but prefers slightly elevated temperatures.

Zooplankton

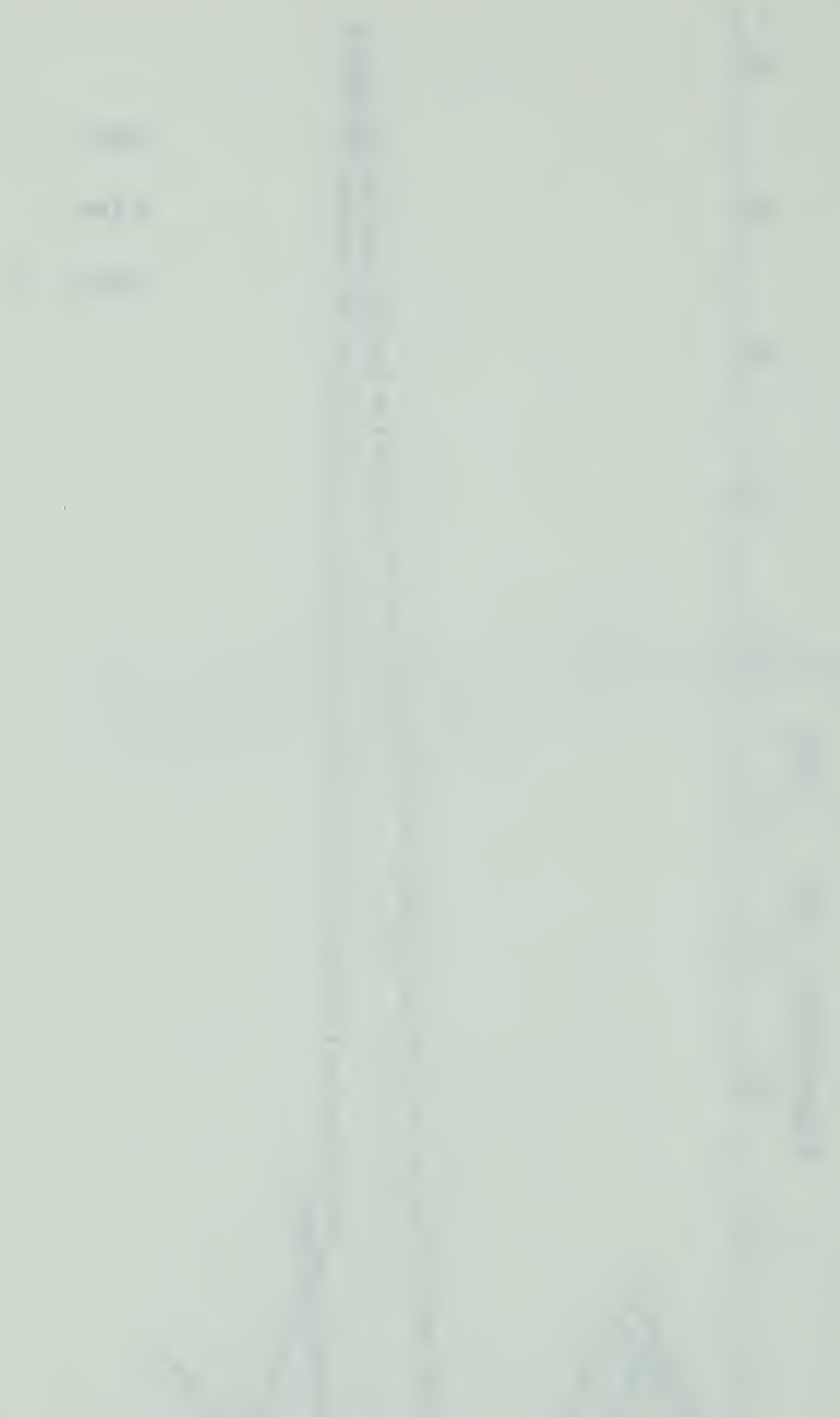
1. Seasonal changes in the Crustacea and Rotifera. The most important members of the zooplankton of Lake Wabamun are the Crustacea and the Rotifera. The animal Protista are also common in the open-water community but Hutchinson (1967) believes that in general they are of lesser importance. The Protozoa found in this study will be treated in the section dealing with surface samples. A list of the various faunal species is found in Appendix IX.

Hutchinson (1967) states that the rotifers are the most important non-arthropod invertebrates in fresh-water plankton. At most times of the year in Lake Wabamun they outnumbered (individuals/litre) the Crustacea (Fig. 30). During the winter, rotifers (mainly *Kellicottia longispina*) far outnumbered the crustaceans. *K. longispina* is known to feed on very small particles such as small algae, small protozoans and bacteria (Edmondson, 1957). It is possible that the success of the rotifers in winter (particularly *K. longispina*) in Lake Wabamun may be due to the presence of very small (1 - 2μ) phytoplankton species, which usually are unrecognisable in preserved samples, but are known to be present in lakes

Fig. 29. Seasonal changes in numbers of *Ceratium hirundinella* at stations 3, 9, and 12, 1970.



Numbers per litre
500
450
400
350
300
250
200
150
100
50
M
J
J
A
S
1970
3
9
12



in winter (Rodhe, 1955). Some of the crustaceans, such as *Daphnia pulex*, cannot use food particles smaller than 1.5μ (Lefèvre, 1942) and hence these tiny phytoplankters may be only taken up by the rotifers.

Shortly after the break-up of ice on the lake there was an almost explosive increase in the rotifer population which reached a maximum of 1075 individuals/litre on May 21 (Fig. 30). The dominant rotifer at this time was again *K. longispina* but large numbers of *Keratella hiemalis* and *Keratella cochlearis* were also present (Plates 11 and 12). These three species have similar feeding habits (Edmondson, 1957).

Only eight days after the rotifers reached a maximum (May 29) the crustaceans had a peak population of 411 individuals/litre (Fig. 30) which at that time largely consisted of nauplii and copepodids, with smaller numbers of cladocerans. The fact that the crustacean numbers reached a peak shortly after the rotifers suggests that the carnivorous cyclopoid copepods present may be using the rotifers as food to a large extent. The cyclopoid copepods are known to prey on rotifers, crustaceans and large algae (Naumann, 1923; Edmondson, 1957).

During the summer period from June 12 to August 27 the numbers of crustaceans (largely Cladocera) generally surpassed those of the rotifers. Hutchinson (1967) notes that there is some competition between the Cladocera and Rotifera for available food particles even though these animals may differ in size by a factor of ten.

Effects of temperature on the various species of Crustacea are being studied by other workers and will not be discussed here.

2. Effects of temperature on selected Rotifera. It has been mentioned previously that the Rotifera is, numerically at least, the most important group of zooplankters present in Lake Wabamun during winter and

Fig. 30. Seasonal changes in numbers of Rotifera and Crustacea, 1970. The points represent means from all stations.

1000
500
NUMBERS PER LITRE
ROTIFERA
CRUSTACEA
J F M A M J J A S
1970

Plate 11. Single specimen of *Keratella hiemalis* (top left); single specimen of same species with amictic egg (top right); single specimen of *Keratella earlinae* (lower left); single specimen of *Keratella cochlearis* with amictic egg (lower right). All about X250.


25 µ

25 µ

25 µ

25 µ

Plate 12. Single specimen of *Filinia longiseta* (top left); two specimens of same species, one with amictic egg (top right); single specimen of carnivorous species *Asplanchna priodonta* (lower left); single specimen of *Kellicottia longispina* with amictic egg (lower right). Various mag. about X250.


50µ


50µ


50µ

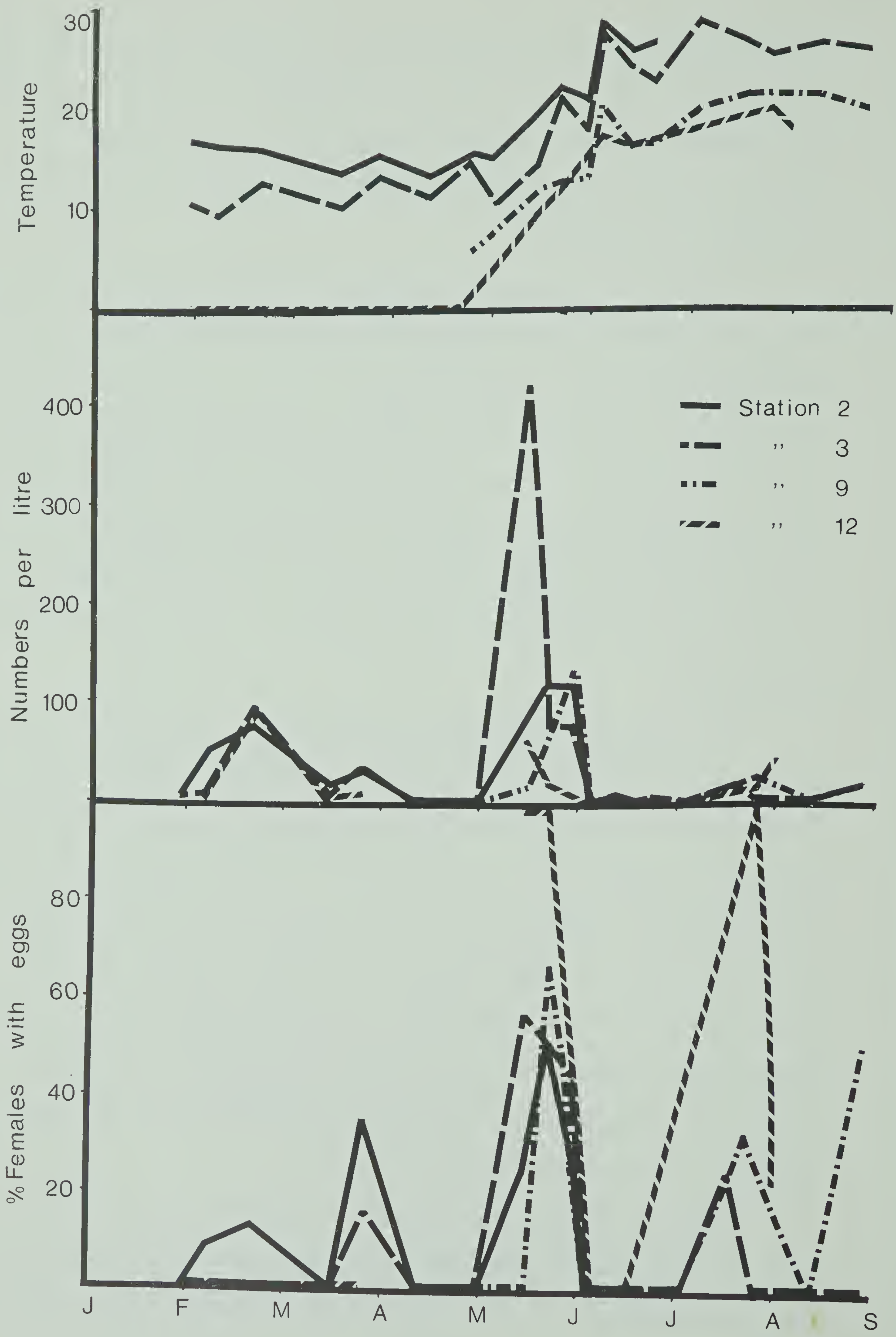

50µ

spring. Edmondson (1946) mentions that the rotifers are very suited to studies of the intermediate levels of production. A total of 47 species was identified from the samples (Appendix IX). It was decided to examine the distribution and occurrence of the nine most common species of rotifers in the lake.

In each of the nine species treated below the effects of temperature on rotifer numbers at four different stations were examined on a seasonal basis (stations 2, 3, 9, and 12; Figs. 31 - 53). These particular stations were regarded as being the most useful in showing the effects of the warmest (station 2), slightly cooler (station 3), intermediate (station 9) and coolest (station 12) temperatures in the lake. Station 1 is actually warmer than station 2, but results from it are disturbed because it is located at the mouth of the outlet canal where strong currents displace the plankton.

The currents are affected by wind and were mentioned in the section dealing with physical characteristics. Station 9, located south of the outlet canal, occasionally receives water warmer than the unaffected lake does (e.g., station 12). Whether or not station 9 receives heated water depends on wind conditions and, hence, currents on any particular date. Much of the water at this station is, however, generally unaffected lake water with only slight temperature increase from the plume of warmed water. Station 9 may therefore be regarded as intermediate in temperature. Station 12 is regarded as being totally unaffected by the effluent and, therefore, is used as a control.

In the 1.5 m. water column, vertical differences in rotifer numbers were not consistently correlated with temperature or depth (Table 9). Sampling errors are greatest when numbers are lowest. The coefficient of



Temperature
30
20
10
Numbers per litre
400
300
200
100
Station 2
" 3
" 9
" 12
% Females with eggs
80
60
40
20
J
F
M
A
M
J
J
A
S

variation was 50 - 75% for populations of 4 - 8 rotifers/litre (Table 9) observed during January and February, and 4.4 - 14.1% for populations of 50 - 250 rotifers/litre observed in May (Table 9).

As well as studying the effects of temperature on numbers of individuals in the various species the effects of the temperature on the egg ratio (egg:females) were examined in five of the nine species (*Kellicottia longispina, Filinia longiseta, Keratella hiemalis, Keratella cochlearis* and *Keratella earlinae*). The egg ratio method gives a measure of the reproductive rate in a natural population (Edmondson, 1965). This rate is temperature sensitive. Higher temperatures result in faster rates of development and shorter life cycles (Edmondson, 1965; Hutchinson, 1967). Males were not observed for any of the rotifer species, so it has been assumed that all the individuals were parthenogenic females and the eggs produced were amictic. The amictic eggs develop in turn into parthenogenic females which upon maturing produce more amictic eggs. It is not possible to separate mature from immature females because they are morphologically similar (Edmondson, 1960). As a result a lower egg ratio is to be expected than if only the mature individuals could be counted. Likewise, senile animals, if present, could not be distinguished, which also decreases the egg ratio.

The remaining four species were compared numerically. Of these two, *Notholca acuminata* and *Polyarthra vulgaris*, did not usually carry their eggs and hence a useful comparison could not be made of the egg ratios at the different stations. *Asplancha priodonta* carries live young and was not observed with eggs. The embryos were sometimes obscured by large food particles (such as other rotifers), therefore they may not always have been counted. Hence, only a numerical comparison was made at the four stations.

Table 9. Differences in rotifer numbers with depth and temperature at two stations, on three sampling dates. Sample numbers are means of triplicates except for station 12, May 21, which are means of duplicates.

Station	Depth, m.	Jan. 31		Feb. 7		May 21	
		T,°C	no./l.	T,°C	no./l.	T,°C	no./l.
2	0	16.8	9.7± 4.2	16.5	70.0±12.2	22.4	173.0±14.2
	0.5	6.5	8.3± 4.8	7.8	42.7± 6.0	22.4	201.0±23.2
	1.0	4.0	39.0±18.2	5.8	29.0±11.4		—
	1.5	3.8	34.0±11.2		—		—
12	0		—	0	4.3± 3.1	12.0	54.5±14.1
	0.5		—	0	27.7± 9.1	12.0	112.0±12.7
	1.0		—	0	13.7± 5.2	12.0	106.0± 1.3
	1.5		—		—	12.0	239.0± 4.4

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The remaining species examined in detail was *Conochilus unicornis*, which is a colonial species and only a numerical comparison was made of this organism also.

a) *Kellicottia longispina* (Kellicott)

Kellicottia longispina dominated the rotifer fauna during most of the study period.

It is easy to calculate the egg ratio for this and the four species following because the females carry the eggs attached to them until they hatch (Edmondson, 1960; Plates 11 and 12). In Lake Wabamun most ovigerous specimens carried a single egg but on rare occasions two eggs per female were noted.

Kellicottia longispina, Keratella cochlearis, Keratella hiemalis, and probably *Keratella earlinae,* have similar eating habits, taking particles smaller than 10 - 12μ in diameter (Hutchinson, 1967; Edmondson, 1960, 1965; and Nauwerk, 1963). The development of *Kellicottia longispina* is somewhat slower than that of *Keratella cochlearis* and *Keratella hiemalis* because the former carries a larger egg (Edmondson, 1960) which may have a greater energy demand on the species. However, in Lake Wabamun, *Kellicottia longispina* still managed to be the dominant species.

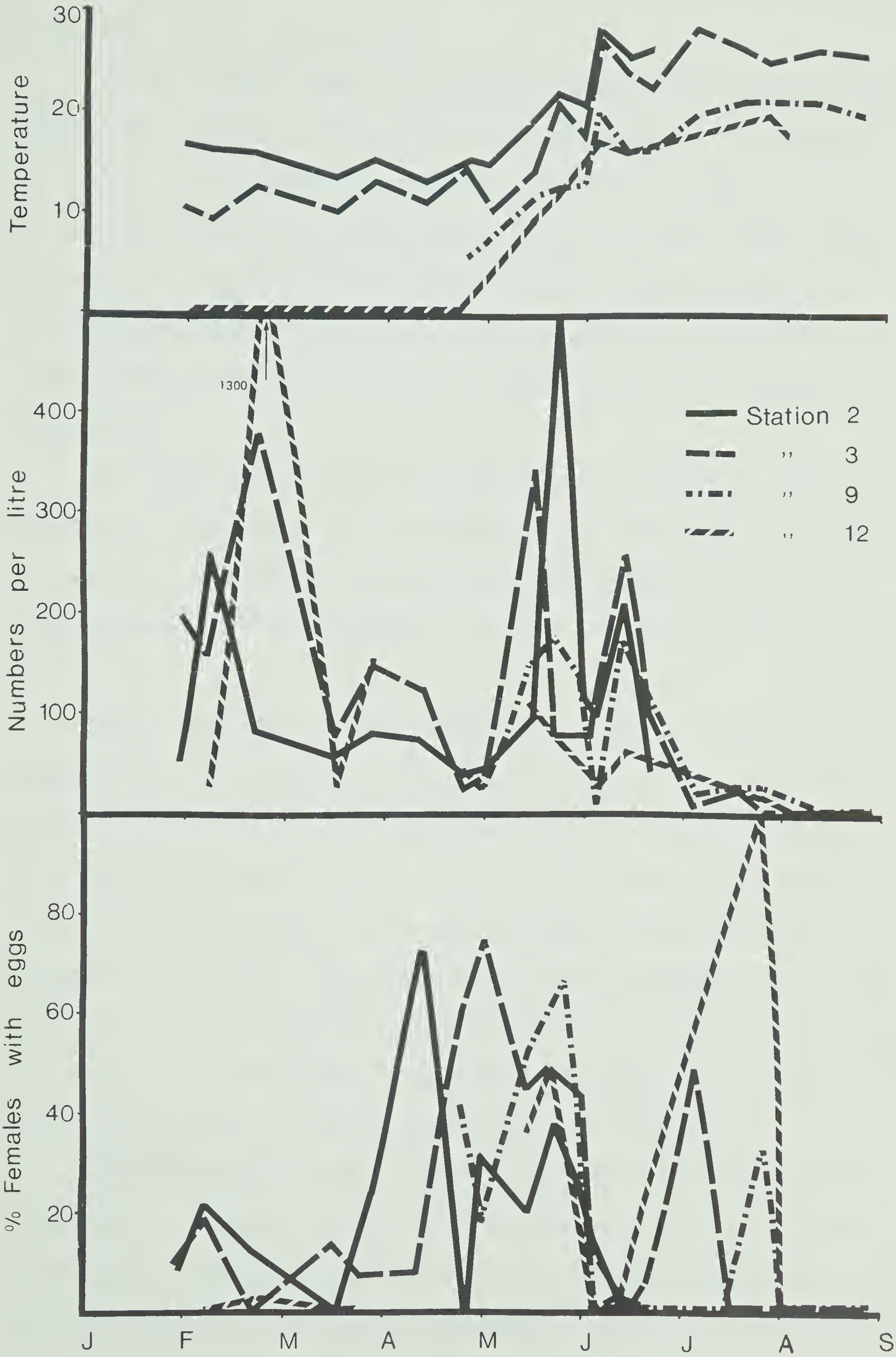
During winter there was an ice cover at station 12 which persisted until about May 1. During winter samples were taken just under the ice at temperatures close to 0 C. Females carried eggs on only February 21 at station 12, when 1300 individuals per litre were found. During this winter period stations 2 (warmest) and 3 (slightly colder) were ice-free and generally had temperatures of 10 C. or greater (Fig. 31). At both stations 2 and 3, females carried eggs during the winter (Fig. 31). Egg production reached a maximum of 73% (ratio of 0.73 eggs/female expressed

as a percentage) on April 11 at station 2. The maximum egg production (75%) was achieved on May 1 at station 3. It is more difficult to decide exactly when greatest reproduction occurred at station 12 because it was impossible to obtain samples there during April as the ice was rotting and unsafe to walk on. Of the samples taken at station 12 the greatest egg production (50%) was recorded on May 21, the same date that the highest percentage of females (67%) carried eggs at station 9. It could be argued that a peak may have occurred in April at both of these stations, although it was impossible to find out because thin ice prevented sampling.

During the period following ice break-up, egg production declined from May 21 at station 12 (Fig. 31). After June 3 no eggs were found on any females. A similar situation occurred at station 9, although on June 12, 3% of the females carried eggs. On June 3, 14% of the females at station 2 carried eggs although on two subsequent dates no eggs were found. Sampling could not be continued at station 2 after June 19 because of the extremely dense masses of vegetation there. At the slightly cooler station 3, eggs were found up to July 3 and no eggs (or adults) were found after this date.

During the winter period (Jan. - end of April), a mean number of 93.1 females/l. were recorded at station 2 compared to a mean of 158.9 females/l. at station 3 and the highest mean of 388.3 females/l. under ice at station 12. During the same period a total mean of 20.0% of the females carried eggs at station 2, 16.9% at station 3, and 0.6% at station 12. Differences between hot and cold stations were not statistically significant at the 5% level. Station 9 was sampled on only one occasion during this period because of a layer of thin ice in that area, so it is not

Fig. 31. Seasonal changes in temperature (C.), numbers of females per litre, and percentage of females with eggs of *Kellicottia longispina* at stations 2, 3, 9, and 12, 1970.



Temperature
30
20
10
Numbers per litre
400
300
200
100
1300
Station 2
,, 3
,, 9
,, 12
% Females with eggs
80
60
40
20
J
F
M
A
M
J
J
A
S

considered for the winter period.

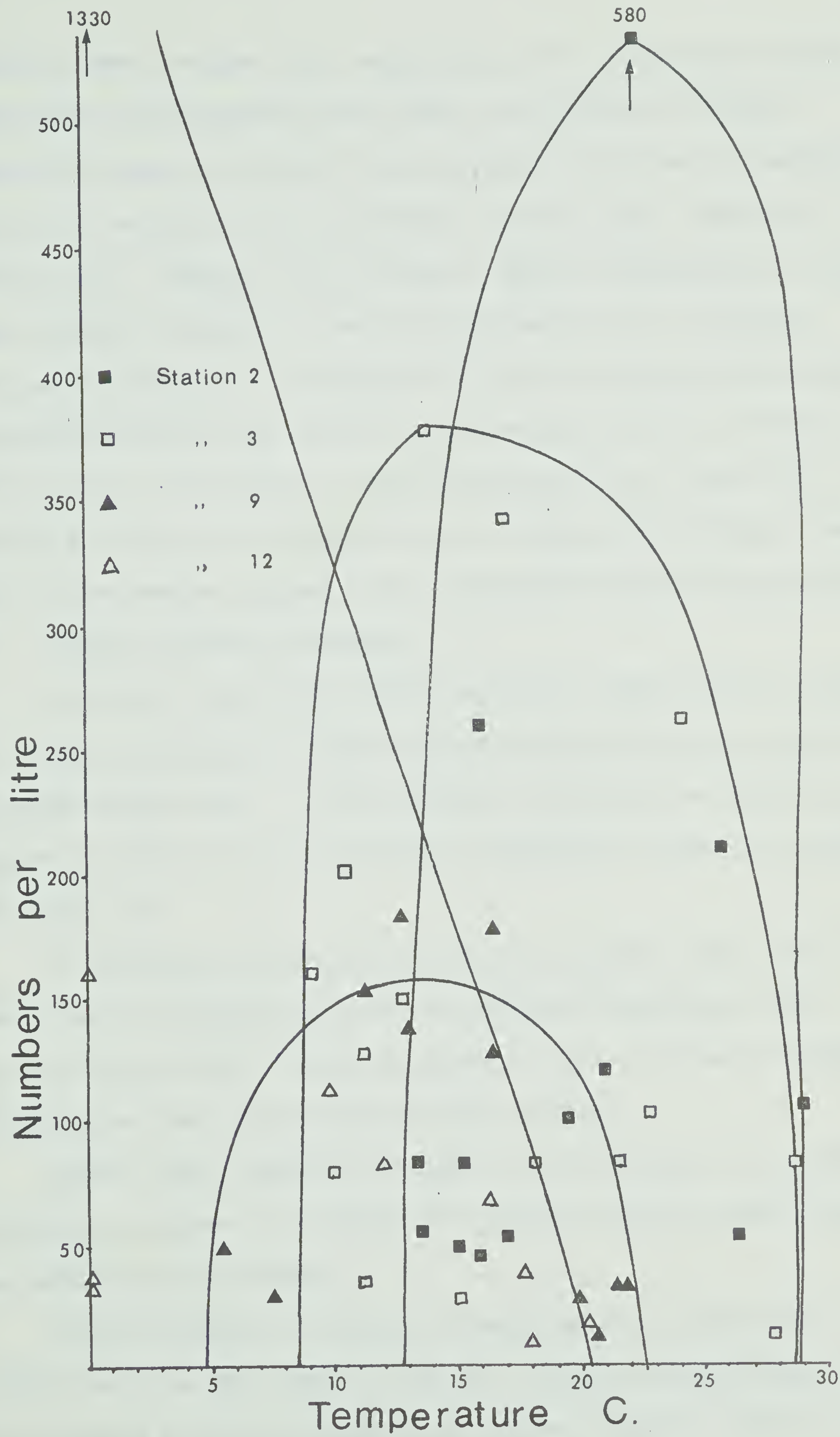
In the ice-free season (from May 1) a mean of 173.1 females/l. was counted from station 2, 89.5 females/l. from station 3, 77.9 females/l. at station 9 and only 52.0 females/l. at station 12. This is very interesting because it is quite the reverse of the trend found during the winter. From May 1 a mean of 18.4% of the females at station 2 carried eggs, 23.5% at station 3, 16.7% at station 9 and the highest mean reading of 31.1% at station 12. These results were not statistically significant.

The annual means were: 133.1 females/l. at station 2, 124.2 females/l. at station 3 and 220.2 females/l. at station 12. During the annual period the means of the per cent carrying eggs at the various stations were: 19.2% at station 2, 21.1% at station 3 and 18.9% at station 12.

During the annual period *K. longispina* occurred in relatively large numbers over a wide range of temperatures (0 - 29 C., Fig. 32). Eggs were produced over the same temperature range with a peak at 22.4 C. (220 eggs/l. and 580 adults/l.). On Feb. 21 a total of 1330 females/l. occurred at 0 C. (station 12) but very few eggs were found at this temperature (Fig. 32). From these data it seems reasonable to conclude that egg production is influenced by temperature. If the Feb. 21 (station 12) result is not considered it is very interesting to note that the greater the heat the greater the adult production of *K. longispina*.

When the relative rate of increase of numbers was plotted against temperature a different pattern (Fig. 33) emerged. Because this rate of change is influenced by a number of factors besides temperature, a close correlation is not expected (Edmondson, 1946). This same author

Fig. 32. Effect of temperature on numbers of adults of *Kellicottia longispina* per litre at stations 2, 3, 9, and 12, 1970.


1330
580
500
450
400
350
300
250
200
150
100
50
Numbers per litre
Station 2
,, 3
,, 9
,, 12
5
10
15
20
25
30
Temperature C.

considers that the upper limit approximates the relationship between temperature and reproductive rate under the conditions existing. Scattering downward from this line represents the action of predation and lack of sufficient food and perhaps sampling error (Edmondson, 1946, and Fig. 33). Stations 2 and 3 showed a similar relationship to temperature although a higher per cent but not greater rate of increase occurred at station 2. At station 9 the rate of change increased with increased temperature up to 15.8 C. and decreased until it reached a peak at 17.8 C. after which it again decreased (Figs. 32 and 33). At station 12 there was a negligible rate of change with increased temperature. These results suggest that *K. longispina* benefits from warmed water.

b. *Filinia longiseta* Ehrenberg

According to Hutchinson (1967) and Pejler (1965) *Filinia longiseta* is mainly a summer form. Ruttner (1937) mentions that this species occurs in deeper colder water. In Lake Wabamun, the species was found in greater numbers in spring and then practically disappeared during the summer of 1970 (Fig. 34).

F. longiseta feeds on small particles including algae, small protozoans, bacteria (Edmondson, 1957) and sediment (Hutchinson, 1967). Perhaps its disappearance during the summer may have been due to competition and predation from crustaceans and other rotifers.

Pejler (1965) regards this species as an indicator of eutrophic conditions. However, the species has also been found in waters which are definitely not eutrophic.

In Lake Wabamun, at station 12 small numbers of individuals were found on only one date (May 21, Fig. 34). Females carrying eggs were also recorded on only one occasion at station 9 (May 29, only one week

Fig. 33. Effect of temperature on the rate of change of population (%/day) of *Kellicottia longispina* at stations 2, 3, 9, and 12, 1970.

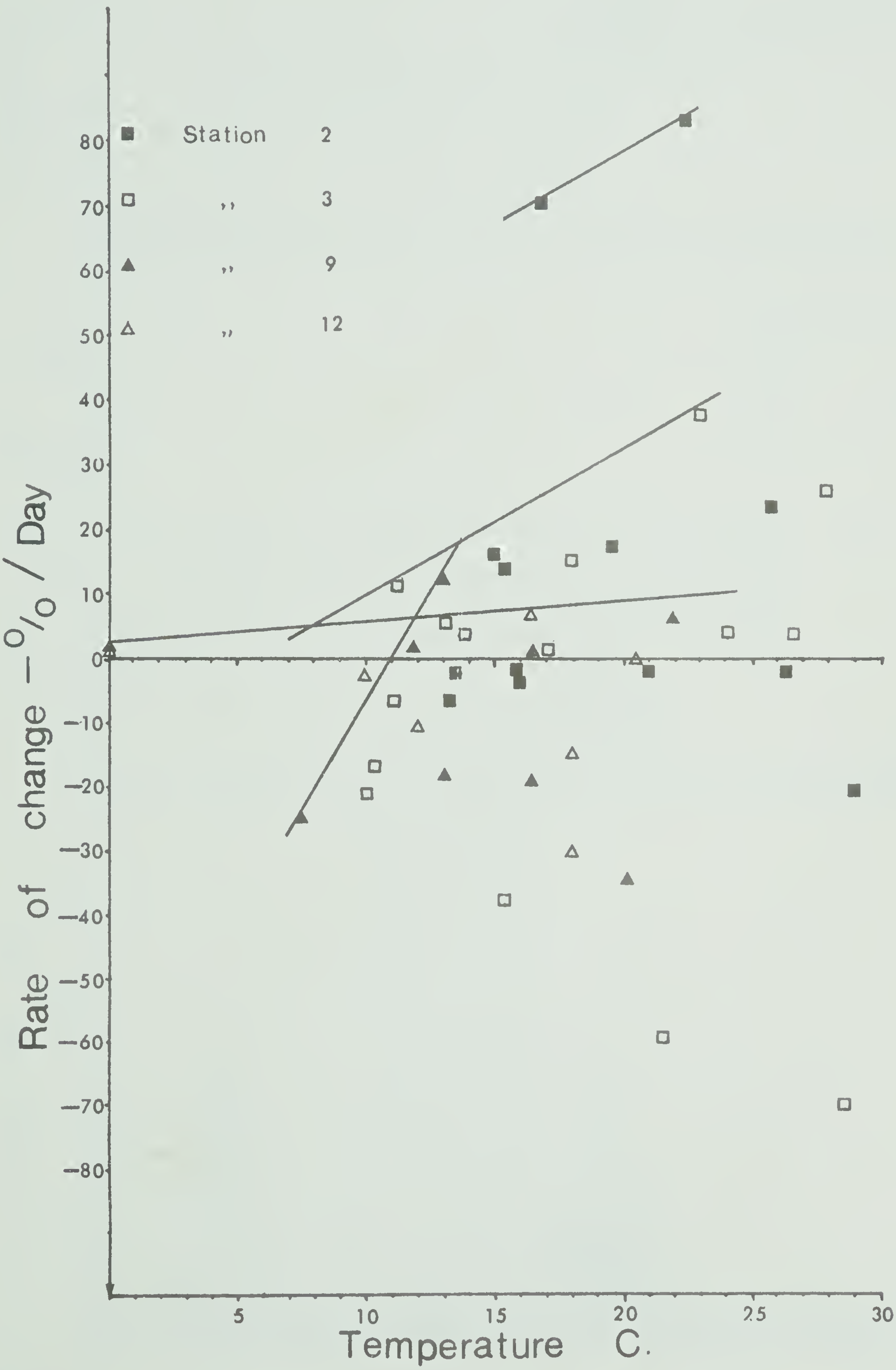
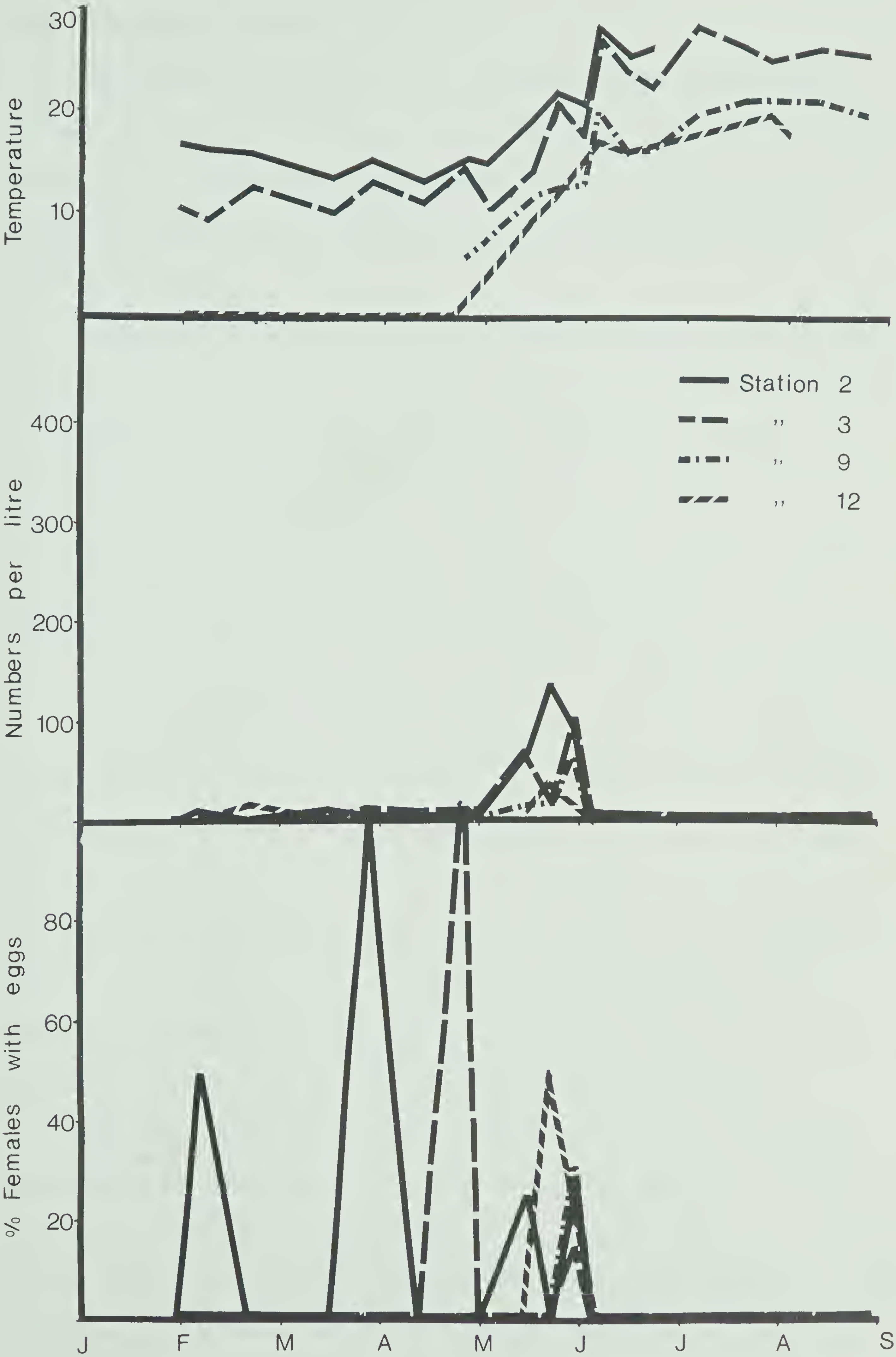

Station 2
,, 3
,, 9
,, 12
Rate of change — °/o / Day
80
70
60
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
5
10
15
20
25
30
Temperature C.

Fig. 34. Seasonal changes in temperature (C.), numbers of females and percentage of females with eggs of *Filinia longiseta* at stations 2, 3, 9, and 12, 1970.



30
20
10
Temperature
Station 2
,, 3
,, 9
,, 12
400
300
200
100
Numbers per litre
80
60
40
20
% Females with eggs
J
F
M
A
M
J
J
A
S

later than that at station 12, Fig. 34).

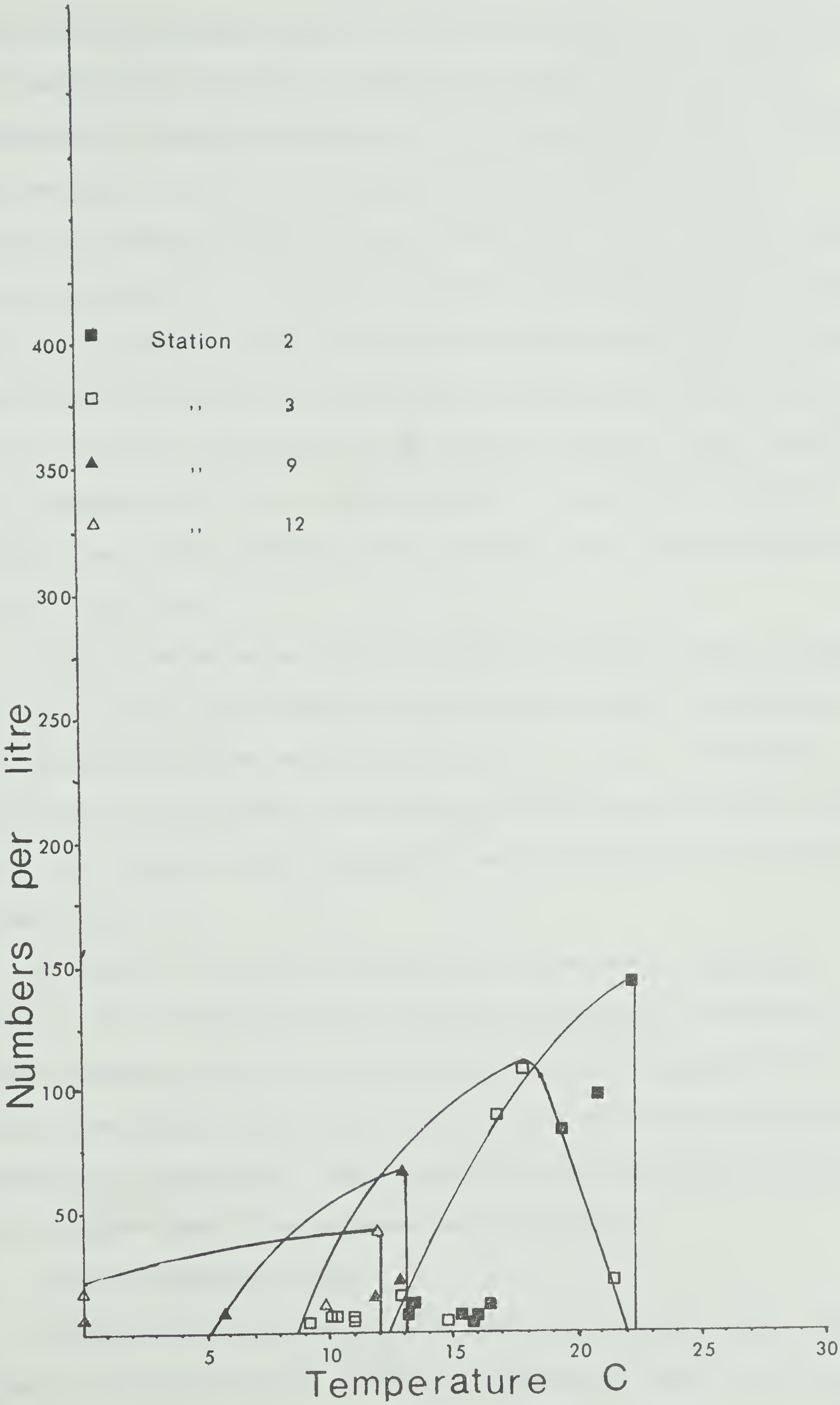
Egg carrying females were more frequently found at the warmer stations (2 and 3). At station 3 eggs were found on two dates (April 24 and May 29, Fig. 34). Up to two eggs per female were seen on April 27. It should be noted that the warmer the station the earlier the egg production occurred.

During winter (Jan. - end of April) the mean numbers of females/l. differed little with 5.3/l. at station 2, 4.9/l. at station 3 and 4.8/l. at station 12. In summer there were some differences (although less than the 5 % level of significance) between the mean numbers of females from warm to cold water; at station 2, 45.0 females/l. station 3, 18.4 females/l., while stations 9 and 12 each had means of 8.3 females/l. Mean numbers of females/l. for the complete sampling season were 25.1/l. at station 2, 12.9/l. at station 3, and 6.9/l. at station 12.

More eggs were found on females during winter in the warmed area, with 21.4% of the females carrying eggs at station 2, 14.3% at station 3, while none at all were recorded at station 12. As with *K. longispina*, the situation was reversed after break-up (from May 1); at station 2, 7.3% of the females carried eggs, 1.2% at station 3, 2.6% at station 9 and 8.3% at station 12, the coldest zone. Mean percentages for the entire study were 14.4% at station 2, 6.0% at station 3, and 5.0% at station 12. These results were not statistically significant.

During the sampling period *F. longiseta* was not found at all at temperatures greater than 22.4 C. (Fig. 35). This would indicate that this species could not tolerate temperatures greater than this, and hence was not present in warmed water during the summer period (Fig. 35). Eggs were found on specimens between 12 and 21 C. This suggests that the

Fig. 35. Effect of temperature on numbers of adults of *Filinia longiseta* per litre at stations 2, 3, 9, and 12, 1970.



Station 2
,, 3
,, 9
,, 12
400
350
300
250
200
150
100
50
5
10
15
20
25
30
Numbers per litre
Temperature C

species can only produce eggs in a very narrow temperature range and that lower temperatures are just as important as higher temperatures in influencing the seasonal occurrence of this interesting animal. Edmondson (1946) mentions that in a laboratory study on a sessile species, *Floscularia conifera*, which had been living at 18 - 20 C. did not feed nor lay eggs at 10 C. A similar reaction could conceivably occur during winter in *F. longiseta* where the animal in warmer water might be producing eggs and after drifting into cooler water the egg production could cease. This is a possible explanation of the absence of eggs at lower temperatures in *F. longiseta* (Fig. 34). Greatest numerical production occurred at stations 2 and 3 with slightly less at station 9 and lowest production at station 12 (Fig. 35).

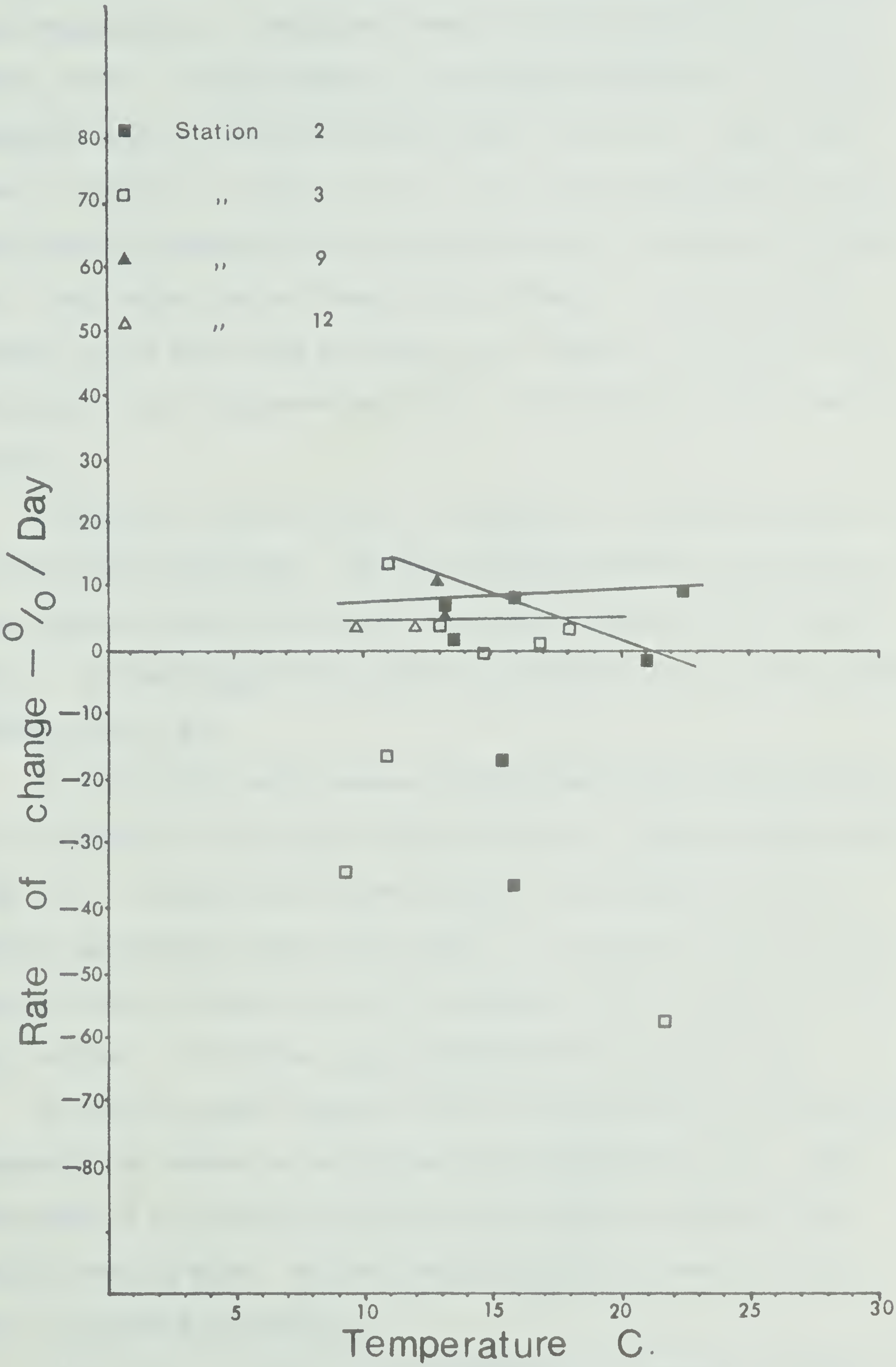
Plotting the relative rate of increase of numbers against temperature (Fig. 36), a very narrow range of temperature was found. Definite boundaries occurred at either end of the scale (9.3 - 22.4 C.) indicating that the species is stenothermal. The absence of the species in water warmer than 22.4 C. indicates that the species has not adapted to the thermal effluent (Fig. 36).

At station 2 the rate of change was unaffected by temperature. At station 3 the rate decreased with increased temperature. Station 9 was the only sampling site at which the rate of change increased with increase in temperature (Fig. 36). At station 12 the rate of change was unaffected by temperature. These results indicate that both coolest as well as warmest water is detrimental to this species.

c. *Keratella hiemalis* Carlin

As mentioned, *Keratella hiemalis* has filter feeding habits similar to both *K. longispina* and *K. cochlearis* (Edmondson, 1960, 1965; Hutchinson,

Fig. 36. Effect of temperature on rate of change of population (%/day) of *Filinia longiseta* at stations 2, 3, 9, and 12, 1970.



Station 2
,, 3
,, 9
,, 12
Rate of change — o/o / Day
80
70
60
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
5
10
15
20
25
30
Temperature C.

1967; Nauwerk, 1963). *K. hiemalis* often has difficulty in colonising an area frequented by *K. longispina* because of the competition for food (Amrèn, 1964). In Lake Wabamun, *K. longispina* outnumbers *K. hiemalis* throughout most of the study season (Figs. 31 and 37). Amrèn (1964) found *K. hiemalis* at a depth of 20 m. in a lake on Spitsbergen and he explained the presence of the species there as an avoidance of competition. Such depths are not found in Lake Wabamun. In addition, the stations in the study area are shallow with samples to only 1.5 m. so that depth is not considered important in distribution in this part of the lake.

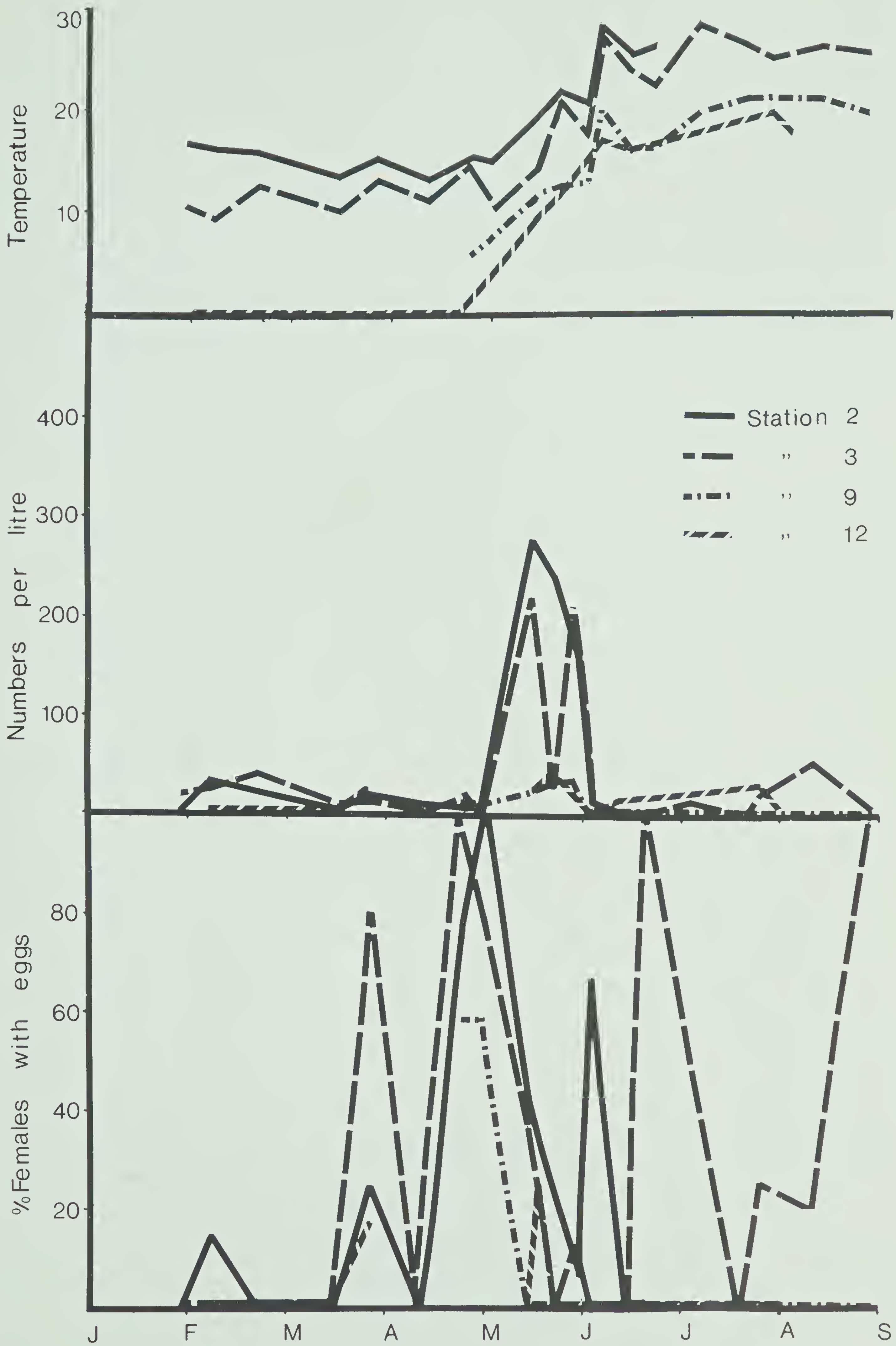
According to Pejler (1957), *K. hiemalis* is a littoral species and a cold-tolerant stenotherm. Williams (1966) describes this species as being common in late fall at many cold water stations in the northern U.S.A. In Lake Wabamun this species was found to have a wide temperature tolerance (Fig. 38).

In this study, small numbers of individuals were found under the ice at station 12, with eggs carried on only one occasion during winter (Fig. 37). A second peak occurred on May 21 and after this date no further egg-carrying females were found. At station 9, eggs were also carried on two occasions but on two successive dates, on April 24 and again on May 1. No further egg-carrying females were observed.

At the two warmer stations (2 and 3) egg production occurred more frequently and numbers of adults were also greater (Fig. 37). Four main peaks of egg production were observed with up to 100% of the females carrying eggs. Earliest egg production was seen at station 2 (Feb. 7) followed by station 3.

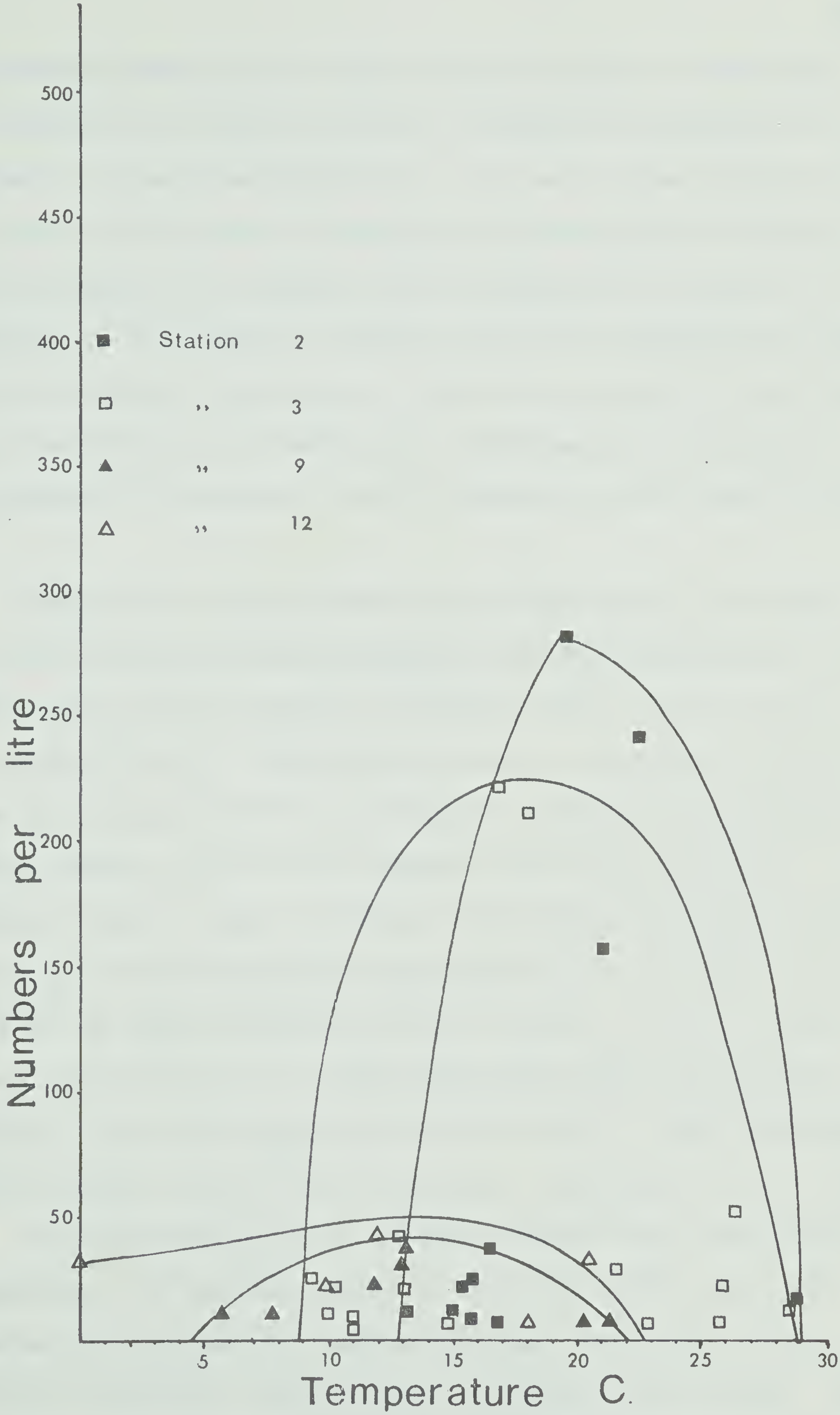
Slight but not statistically different mean numbers of adults at

Fig. 37. Seasonal changes in temperature (C.), numbers of females and percentage of females with eggs of *Keratella hiemalis* at stations 2, 3, 9, and 12, 1970.



Temperature
30
20
10
Numbers per litre
400
300
200
100
Station 2
" 3
" 9
" 12
%Females with eggs
80
60
40
20
J
F
M
A
M
J
J
A
S

Fig. 38. Effect of temperature on numbers of adults of *Keratella hiemalis* per litre at stations 2, 3, 9, and 12, 1970.



Station 2
,, 3
,, 9
,, 12
Numbers per litre
500
450
400
350
300
250
200
150
100
50
5
10
15
20
25
30
Temperature C.

the stations during winter: means of 14.3 females/l. at station 2, 17.0 females/l. at station 3 and only 7.3 females/l. under the ice at station 12. After break-up (from May 1) the means showed greater differences: 87.5 females/l. at station 2, 46.2 females/l. at station 3, only 8.6 females/l. at station 9 and 18.3 females/l. at station 12. The difference in mean numbers at stations 2 and 9 were significantly different at the 10% level of significance. Greatest mean numbers for the annual period were found in the heated zone: 53.3 females/l. at station 2, 35.4 females/l. at station 3, and 13.9 females/l. at the cooler station 12.

During winter some differences (not statistically significant) were noted between the mean percentage of females carrying eggs in the warmer areas (16.6% at station 2, 25.9% at station 3) and the normal lake at station 12 (4.4%). After break-up, however, there were some differences with a mean of 34.4% of the females at station 2 carrying eggs, 35.0% at station 3, only 4.9% at station 9, and 4.2% at station 12. At station 9 eggs were found on females on only one of the sampling dates. These results were statistically significant to the 5% level or less. Means for the annual period were 25.5% at station 2, 31.6% at station 3, and 4.3% at station 12. Differences in the annual means between stations 2 and 12 were significant to the 5% level. Annual differences between stations 3 and 12 were statistically significant at the 1% level.

Over the annual period *K. hiemalis* occurred over a wide range of temperatures with greatest numbers at 19.5 C. (Fig. 38). Eggs were produced over the same wide temperature range. This species did not show the stenothermal characteristics mentioned by Pejler (1957). This suggests that the species may have adapted to the unnatural situation

found in Lake Wabamun. Greatest production was found in the warmest waters (stations 2 and 3, Fig. 38). Smaller maxima occurred at stations 9 and 12 (Fig. 38).

The relative rate of change plotted against temperature had an upper boundary similar to that of *F. longiseta* (Figs. 36 and 39). *K. hiemalis* had a wider range of change and a greater temperature tolerance than *F. longiseta*.

The positive rate of change was greatest at station 9 (Fig. 39). However, these rates decreased with increased temperature at stations 2, 3, and 9. At station 12 rates were negative at lower temperatures but increased with increasing temperature (above 12 C.). These results indicated that although warm temperatures are tolerated, the species prefers water at station 12 above 12 C. (Fig. 39).

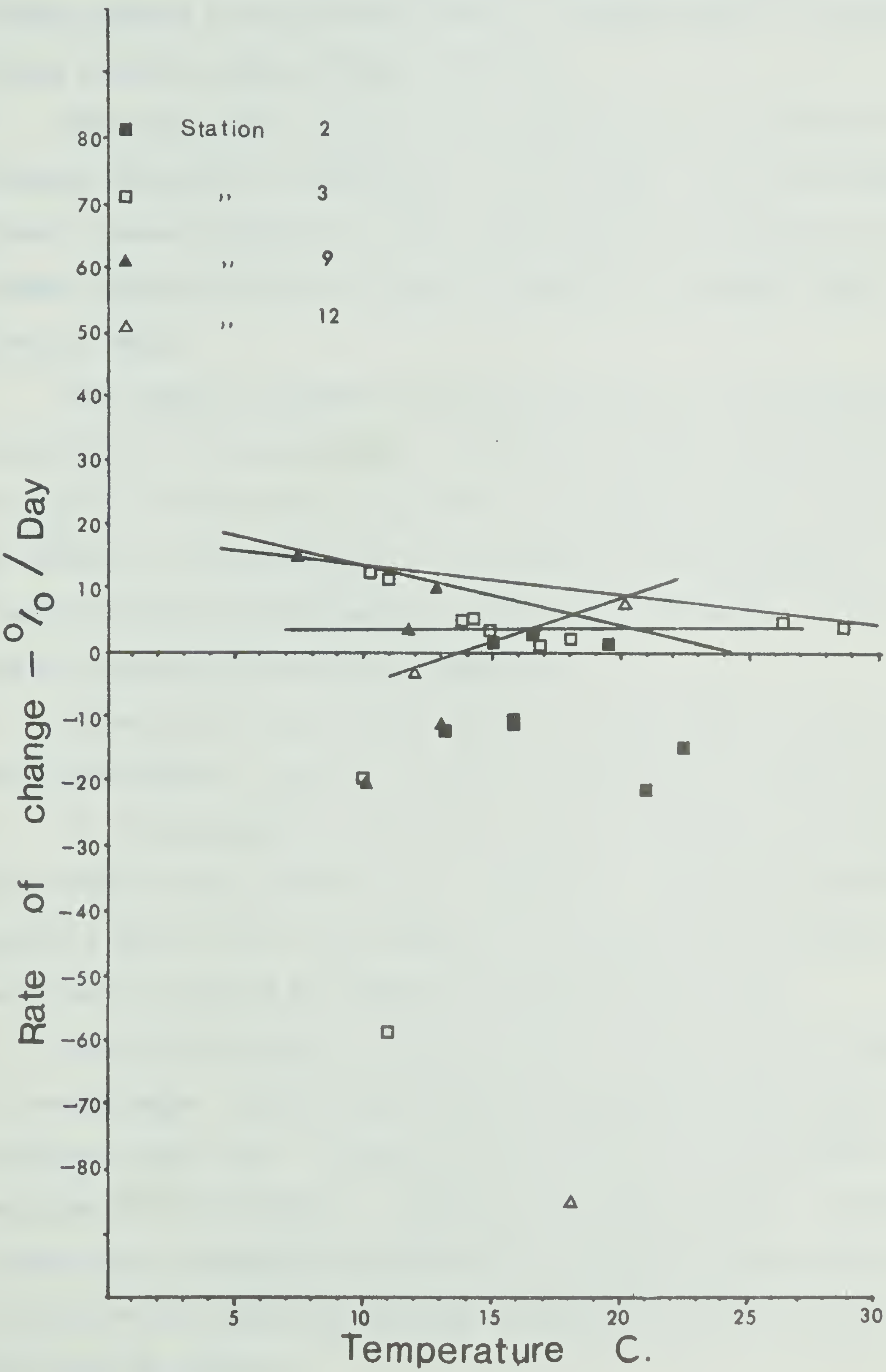
d. *Keratella cochlearis* Gosse

Keratella cochlearis is an almost ubiquitous species (Hutchinson, 1967) and may be the most common species of rotifer in the world (Ahlstrom, 1940). It is a morphologically variable species and it is possible that differences will occur in the rate of development of different populations (Edmondson, 1960).

As mentioned, the food of *K. cochlearis* consists of small µ-algae and particles the same size as those grazed on by *K. longispina* and *K. hiemalis* (Edmondson, 1957).

Specimens of both *K. cochlearis* and *K. earlinae* were seen inside the stomach of the voracious carnivore *Asplanchna priodonta*. However, it is possible that little effect was shown by this predator on *K. cochlearis* because *A. priodonta* was more frequently seen carrying diatoms and other algae in its stomach than *K. cochlearis* or *K. earlinae*. It

Fig. 39. Effect of temperature on the rate of change of population (%/day) of *Keratella hiemalis* at stations 2, 3, 9, and 12, 1970.



Station 2
,, 3
,, 9
,, 12
Rate of change — °/o / Day
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
5
10
15
20
25
30
Temperature C.

is interesting to note that *K. hiemalis* was never found in *A. priodonta*, perhaps because it may be more difficult to swallow with its two widely spaced posterior spines (Plates 11 and 12).

Edmondson (1960) reported that reproduction of *K. cochlearis* is strongly influenced by temperature and food supply. The same author found a lowered production at lower temperatures. The species is eurythermal and may be found in either oligotrophic or eutrophic lakes (Pejler, 1962).

Mean numbers of females during winter were: 25.1 individuals/l. at station 2, 20.9 individuals/l. at station 3 and 25.3 individuals/l. at station 12. After break-up (from May 1) the means were 46.4 individuals/l. at station 2, 52.5 individuals/l. at station 3, 24.6 individuals/l. at station 9 and 24.4 individuals/l. at the control station 12. These results were not statistically significant.

Means for the annual period were 35.6 individuals/l. (station 2), 40.8 individuals/l. (station 3) and 24.6 individuals/l. (station 12).

It is interesting to note that no eggs were found on any females from samples taken under the ice at station 12. During the same winter period a mean of 8.2% of the females in the heated zone at station 2 and a mean of 2.3% of the females at station 3 carried eggs.

After break-up (May 1) a mean of 53.7% of the females at station 12 carried eggs. On three dates 100% of the females carried eggs at station 12 (Fig. 40). At station 9 a mean of 16.3% of the females carried eggs and 14.7% at station 2. Station 3 had a mean of 14.3%. These results had no statistical significance. During the annual period a mean of 32.2% of the females carried eggs at station 12, 10.1% at station 3, and 11.3% at station 2.

Fig. 40. Seasonal changes in temperature (C.), numbers of females and percentage of females with eggs of *Keratella cochlearis* at stations 2, 3, 9, and 12, 1970.

Plotting numbers/l. against temperature, females of *K. cochlearis* were found over the complete temperature range (0 - 29 C.). Greatest numbers were found at 16.8 C. (station 3, Fig. 41). Peak numbers of eggs were found at the same temperature. No eggs were seen on any specimens at temperatures below 9.8 C. or above 26.6 C. It is possible that at lower temperatures egg production ceases as was indicated for *F. longiseta* (Fig. 40). The apparent range of temperature tolerance for the eggs is greater for *K. cochlearis* than for *F. longiseta*.

Plotting the relative rate of change in numbers against temperature (Fig. 42) there is a slight tendency for the rate to rise with increase in temperature but not nearly as steeply as for *K. longispina* (Fig. 33). This could possibly indicate that *K. cochlearis* is somewhat less sensitive to temperature change than *K. longispina*, although both species apparently tolerate the wide range of temperatures they experience.

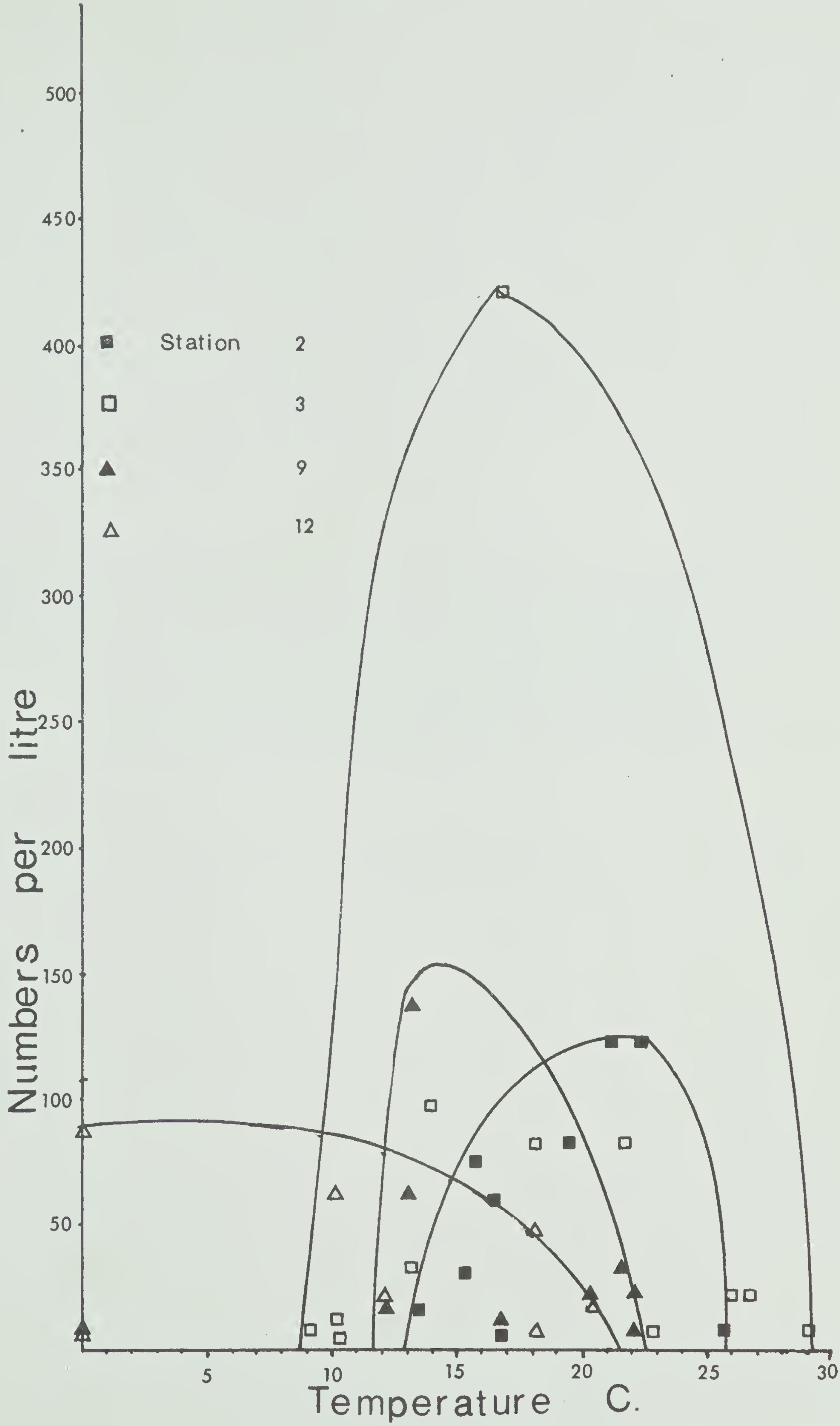
The positive rate of change was slightly greater at station 3 than at the other stations, up to 18 C. At temperatures greater than this the rate declined rapidly at station 3 but increased slightly at stations 2 and 9. At station 12 the rate of change remained steady over the normal temperature range of the lake.

e. *Keratella earlinae* Ahlstrom

According to Ahlstrom (1943) *K. earlinae* has been observed in material collected from April to September but in Lake Wabamun the species was collected in February also (Fig. 43).

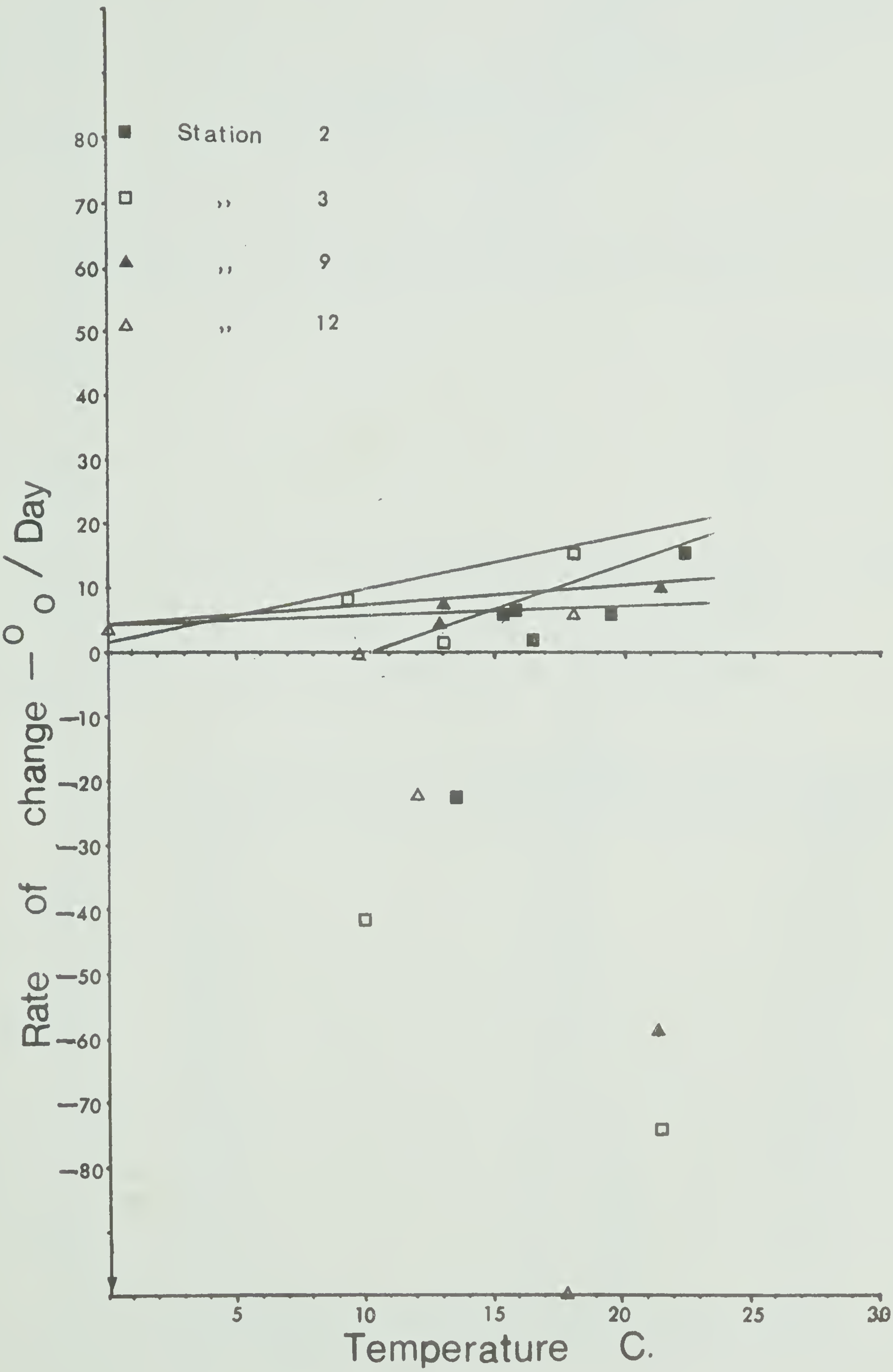
In Lake Wabamun, *K. earlinae* was less common than *K. cochlearis* (Figs. 40 and 43) although their periods of occurrence overlapped. Greatest numbers of both species were found after the spring break-up.

Fig. 41. Effect of temperature on numbers of adults of *Keratella cochlearis* per litre at stations 2, 3, 9, and 12, 1970.



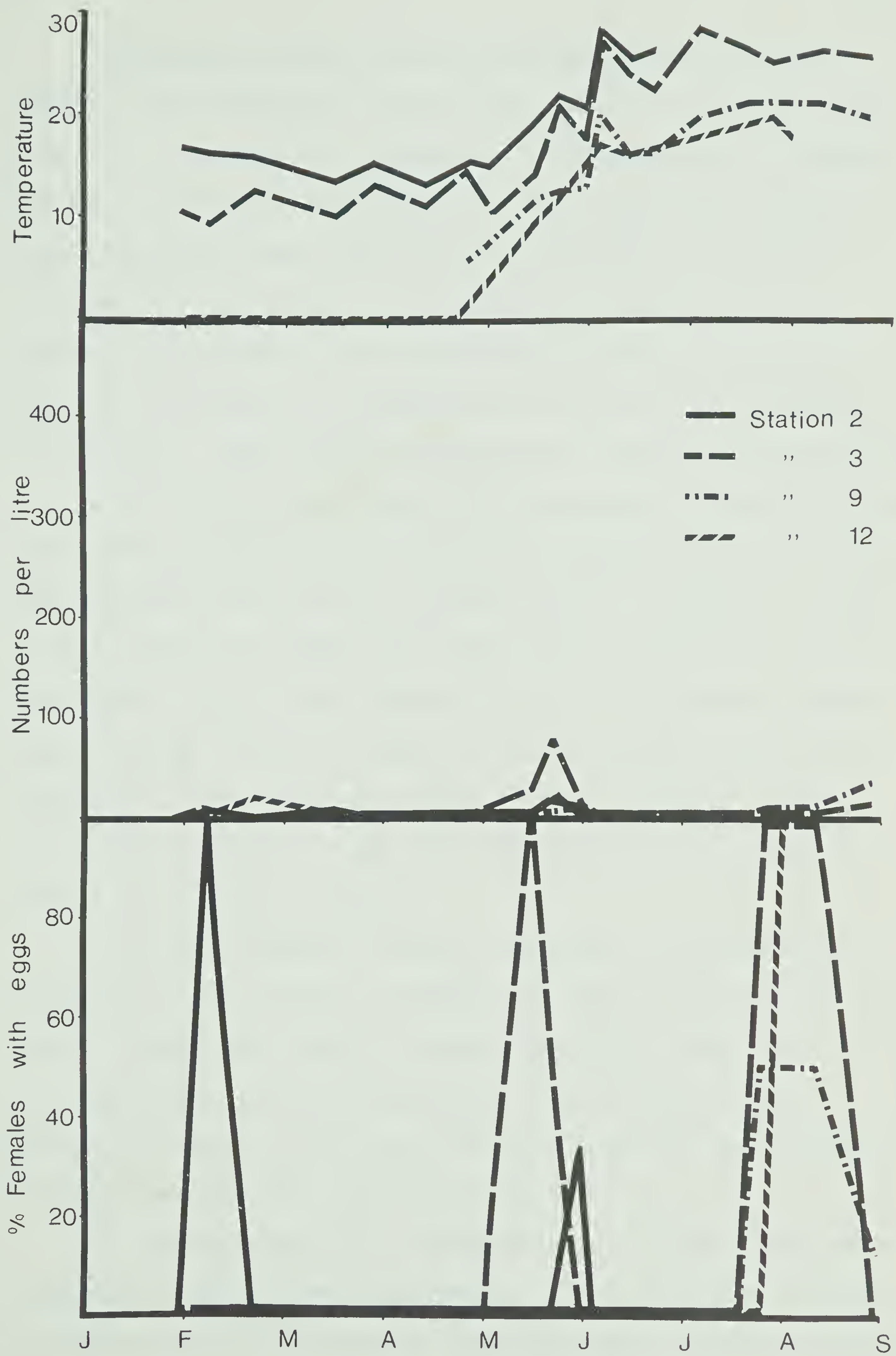
Station 2
3
9
12
Numbers per litre
Temperature C.
500
450
400
350
300
250
200
150
100
50
5
10
15
20
25
30

Fig. 42. Effect of temperature on the rate of change of population (%/day) of *Keratella cochlearis* at stations 2, 3, 9, and 12, 1970.

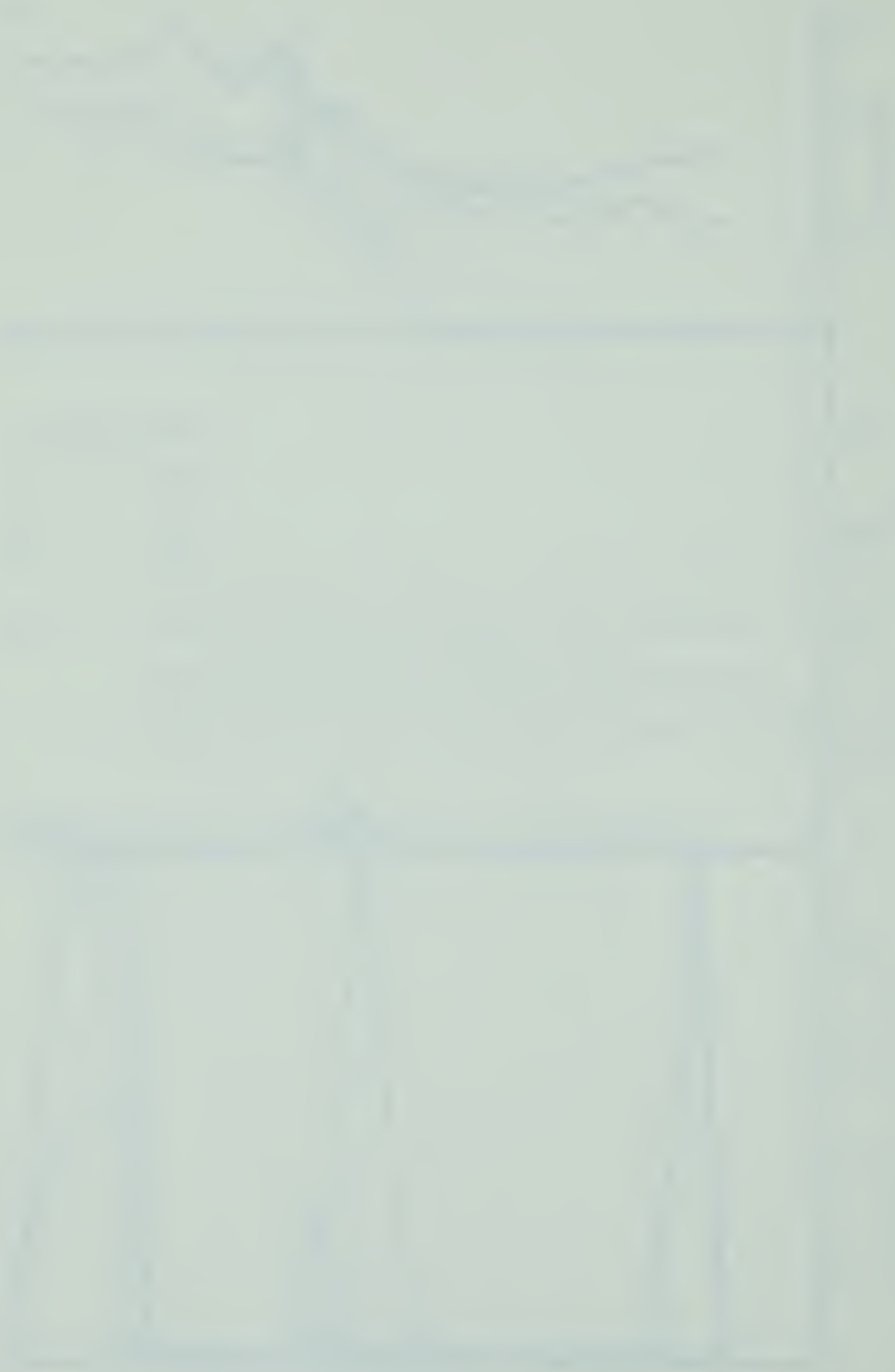


Station 2
,, 3
,, 9
,, 12
Rate of change — $^0/_0$ / Day
80
70
60
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
5
10
15
20
25
30
Temperature C.

Fig. 43. Seasonal changes in temperature (C.), numbers of females and percentage of females with eggs of *Keratella earlinae* at stations 2, 3, 9, and 12, 1970.



30
20
10
Temperature
400
300
200
100
Numbers per litre
Station 2
" 3
" 9
" 12
80
60
40
20
% Females with eggs
J
F
M
A
M
J
J
A
S



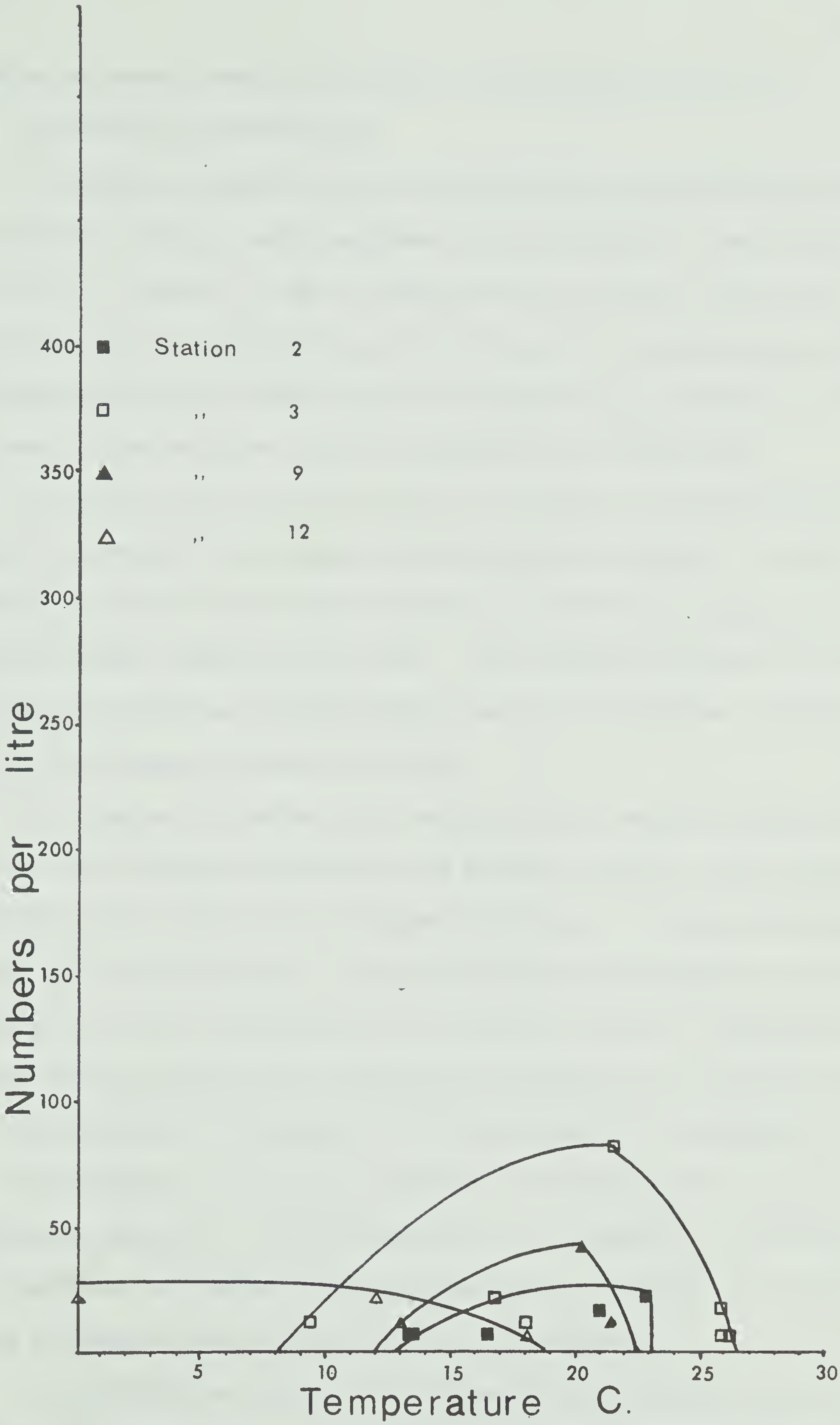
During winter numbers were small and mean numbers of females differed little between the warm and cold stations. At station 2 the mean was 2.1 individuals/l., compared to 1.4 individuals/l. at station 3 and 2.9 individuals/l. at station 12. Mean numbers were slightly higher during the summer with means of 5.0 females/l. at station 2, 11.3 females/l. at station 3, 5.8 females/l. at station 9 and 4.2 females/l. at station 12. The means for the annual period were 3.0 females/l. at station 2, 7.6 females/l. at station 3 and 4.5 females/l. at station 12. None of these differences were statistically significant.

Some differences were found in the percentages of females carrying eggs. During winter a mean of 14.3% of the females at station 2 carried eggs compared to none at all at stations 3 and 12. However, it should be kept in mind that numbers were small and this might tend to distort the results. In the summer (from May 1), 4.8% of the females carried eggs at station 2, 29.2% at station 3, 9.4% at station 9 and 10.0% at station 12. Annual means were 9.5% at station 2, 18.4% at station 3 and 10.0% at station 12. Again small numbers could be the cause of some of the variation in numbers.

Plotting the numbers/l. against temperature, it was found that *K. earlinae* adults occurred at temperatures from 0 to 25.5 C. (Fig. 44). Greatest numbers were found at a temperature of 18 C. (Fig. 44). It is interesting to note that the greatest maximum number of adults occurred at station 3 with less at station 9 and fewest at the warmest (station 2) and coolest (station 12) (Fig. 44).

K. earlinae as well as *F. longiseta* and *K. cochlearis* cease egg production at normal winter temperatures. The relative rate of change in numbers was not plotted against temperature for *K. earlinae* and the

Fig. 44. Effect of temperature on numbers of adults of *Keratella earlinae* per litre at stations 2, 3, 9, and 12, 1970.



Numbers per litre
400
350
300
250
200
150
100
50
Station 2
,, 3
,, 9
,, 12
5
10
15
20
25
30
Temperature C.

species following because the numbers involved were rather low.

f. *Asplanchna priodonta* Gosse

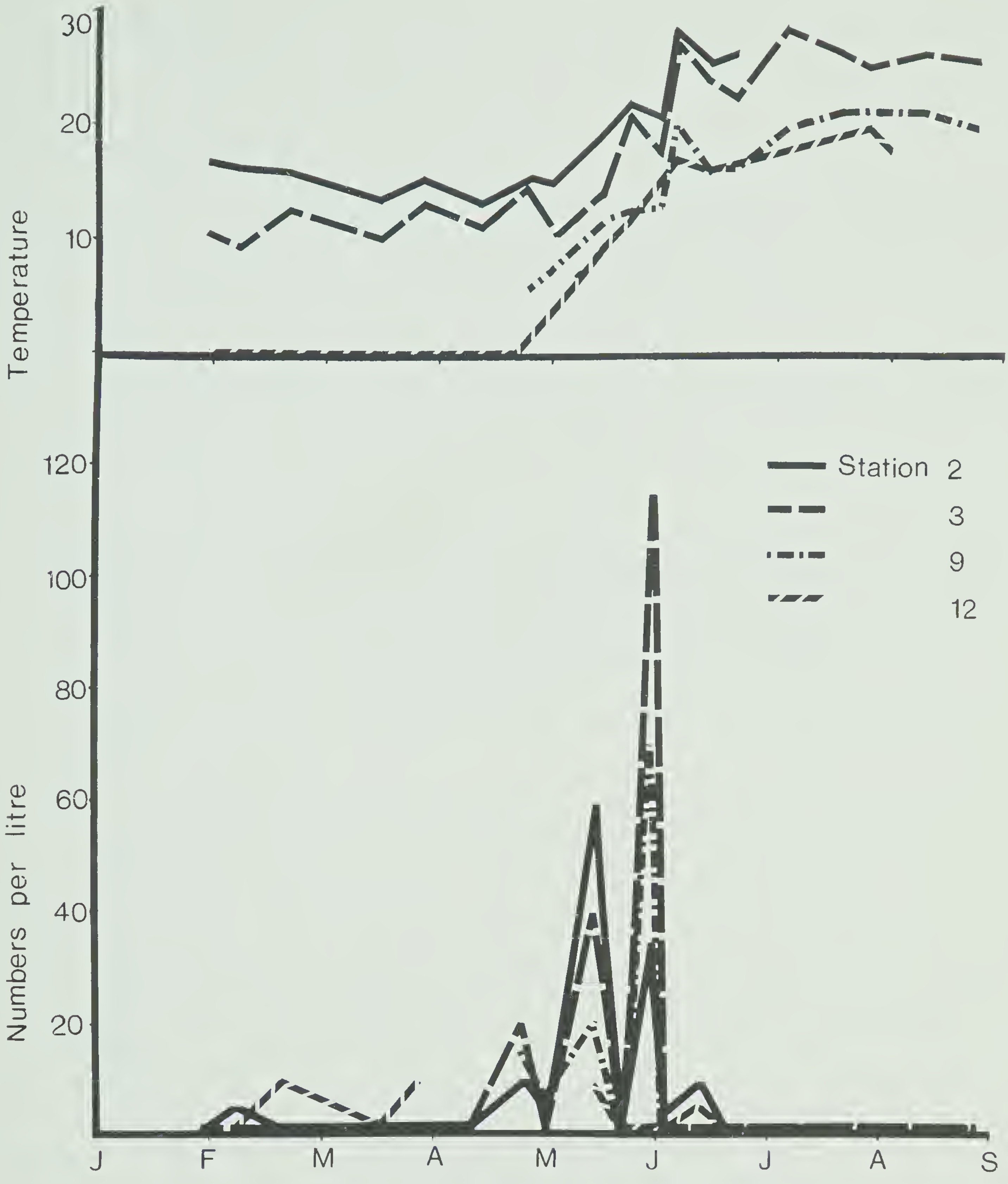
Asplanchna priodonta is quite different from the preceding species in some ways, being a large carnivore and producing live young (Plates 11 and 12). However, it had a somewhat similar seasonal cycle to *K. cochlearis* and *K. earlinae* (Figs. 40, 43 and 45). As mentioned, both of these species were found inside the stomach of *A. priodonta*, as well as some diatoms and other algae too digested to be identified.

Hutchinson (1967) mentions that *A. priodonta* has somewhat sharper maxima (in numbers) than those of other perennial species. In Lake Wabamun, after the main maximum occurred in late May the species disappeared almost completely (Fig. 45). This pattern is similar to one described by Hutchinson (1967) except that the main maximum occurred in May in Lake Wabamun instead of in July.

Only numbers of adults of *A. priodonta* were compared because the embryos were sometimes obscured by the stomach contents, and so embryo to adult ratios could not be calculated accurately. During the winter a mean of 5.0 individuals/l. was found at station 12 compared to lower means of 2.2 and 2.9 individuals/l. at stations 2 and 3, respectively. After break-up greatest mean numbers were recorded in the warmer area: 16.4 individuals/l. at station 2, 12.9 individuals/l. at station 3, 7.9 individuals/l. at station 9 and only 2.5 individuals/l. at the unaffected station 12. Annual means were: 9.3 females/l. at station 2, 9.2 females/l. at station 3 and 3.5 females/l. at station 12. None of these differences were within 5% range of significance.

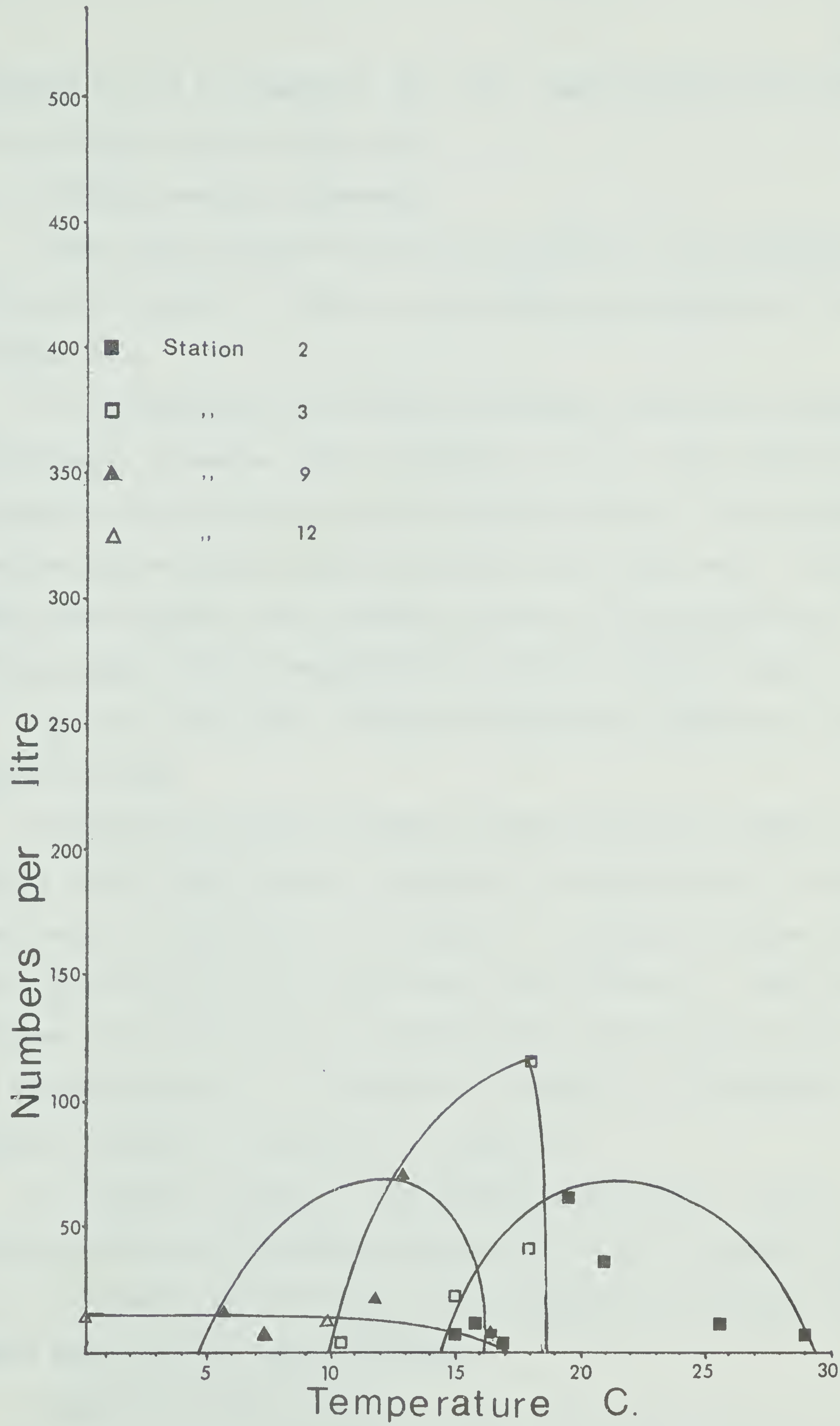
A. priodonta was found at all temperatures occurring in the lake (Fig. 46). Greatest numbers were found at intermediate temperatures with

Fig. 45. Seasonal changes in temperature (C.), numbers of females of *Asplanchna priodonta* at stations 2, 3, 9, and 12, 1970.



Temperature
30
20
10
Numbers per litre
120
100
80
60
40
20
Station 2
3
9
12
J
F
M
A
M
J
J
A
S

Fig. 46. Effect of temperature on numbers of adults of *Asplanchna priodonta* per litre at stations 2, 3, 9, and 12, 1970.



Numbers per litre
500
450
400
350
300
250
200
150
100
50
Station 2
,, 3
,, 9
,, 12
5
10
15
20
25
30
Temperature C.

a maximum at 21.5 C. (station 2, Fig. 46). Fewest specimens were found at the coldest station 12 (Fig. 46).

g. *Notholca acuminata* (Ehrenberg)

Carlin (1943) describes *Notholca acuminata* as a cold stenotherm. This species occurred in winter in Lake Wabamun and disappeared in late May (Fig. 47).

It is interesting to note that *N. acuminata* was found in greatest concentration in samples which were muddy or silty. Pejler (1962) found the species in fine detritus gyttja in Swedish waters. It is possible that the species feeds on minute particles in the dirty water. Pejler (1962) found diatoms in the stomachs of some of his specimens but no distinguishable food was recognised from the Lake Wabamun samples.

Eggs were rarely seen. Because of this only a comparison of adult females was made.

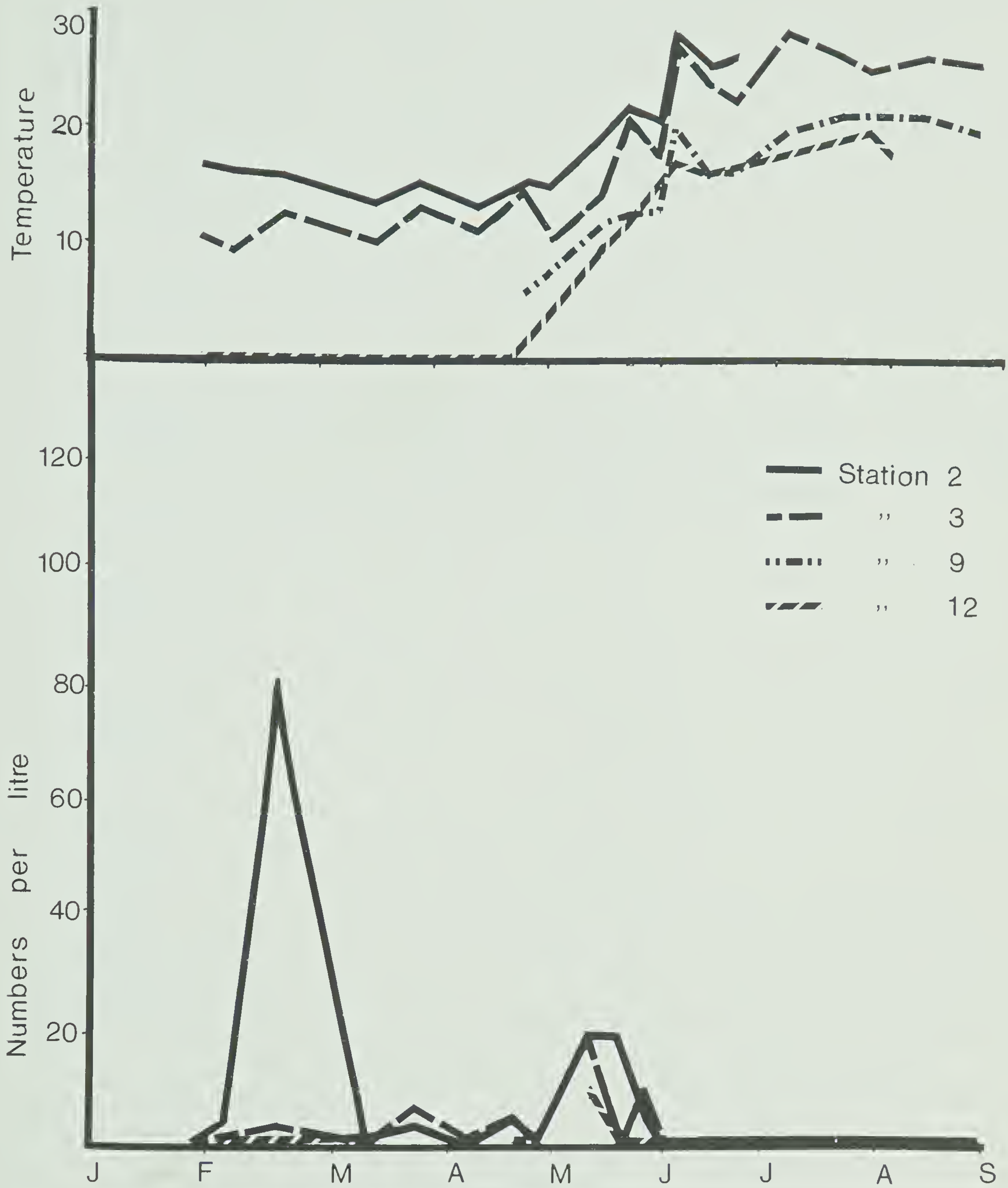
Greatest mean numbers of females occurred during the winter at station 2 (13.9 individuals/1.) compared to 2.6 individuals/1. at station 3 and only 0.4 individuals/1. at station 12. Differences between stations 3 and 12 were statistically significant at the 10% level. After break-up the means were lower because no specimens were found from the end of May. The annual means were: 10.3 females/1. at station 2, 2.6 females/1. at station 3 and only 1.2 females/1. at station 12.

N. acuminata occurred at temperatures ranging from 0 - 22.4 C. with greatest numbers at intermediate temperatures (12 - 17 C. approx., Fig. 48). This species does not appear to have adapted to the highest temperatures found with the thermal effluent.

h. *Polyarthra vulgaris* Carlin

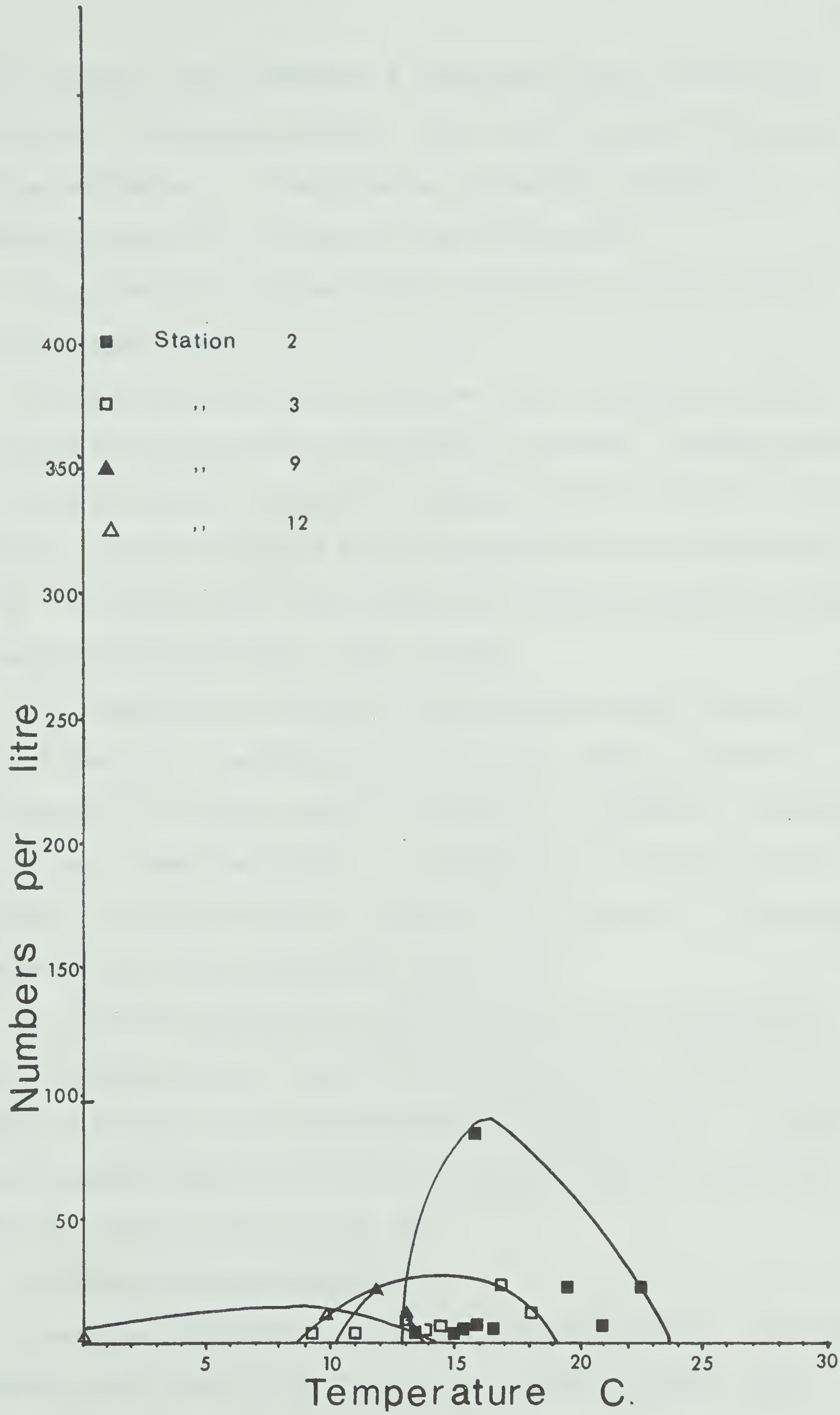
Polyarthra vulgaris is a perennial species usually having a maximum

Fig. 47. Seasonal changes in temperature (C.), numbers of females of *Notholca acuminata* at stations 2, 3, 9, and 12, 1970.



30
20
10
Temperature
120
100
80
60
40
20
Numbers per litre
Station 2
,, 3
,, 9
,, 12
J
F
M
A
M
J
J
A
S

Fig. 48. Effect of temperature on numbers of adults of *Notholca acuminata* per litre at stations 2, 3, 9, and 12, 1970.


Station 2
,, 3
,, 9
,, 12
Numbers per litre
400
350
300
250
200
150
100
50
5
10
15
20
25
30
Temperature C.

in late spring or early summer in a temperature range from below 15 C. to about 20 C. (Hutchinson, 1967). Pejler (1956) regards this species as being eurythermal. In Lake Wabamun the maximum occurred at a temperature of 21.0 C. at station 3 (Figs. 49 and 50).

No egg ratio is included in the data for this species because eggs were rarely seen.

No specimens were found at stations 2 and 3 during the winter. At station 12 a mean of only 1.0 females/l. occurred. The first specimens were found at station 2 on May 14. Specimens were not found at station 3 until May 21 and at station 9 the first specimens were not seen until May 29. From this date it seems likely that initial increase in numbers is temperature sensitive (14 - 22 C. range).

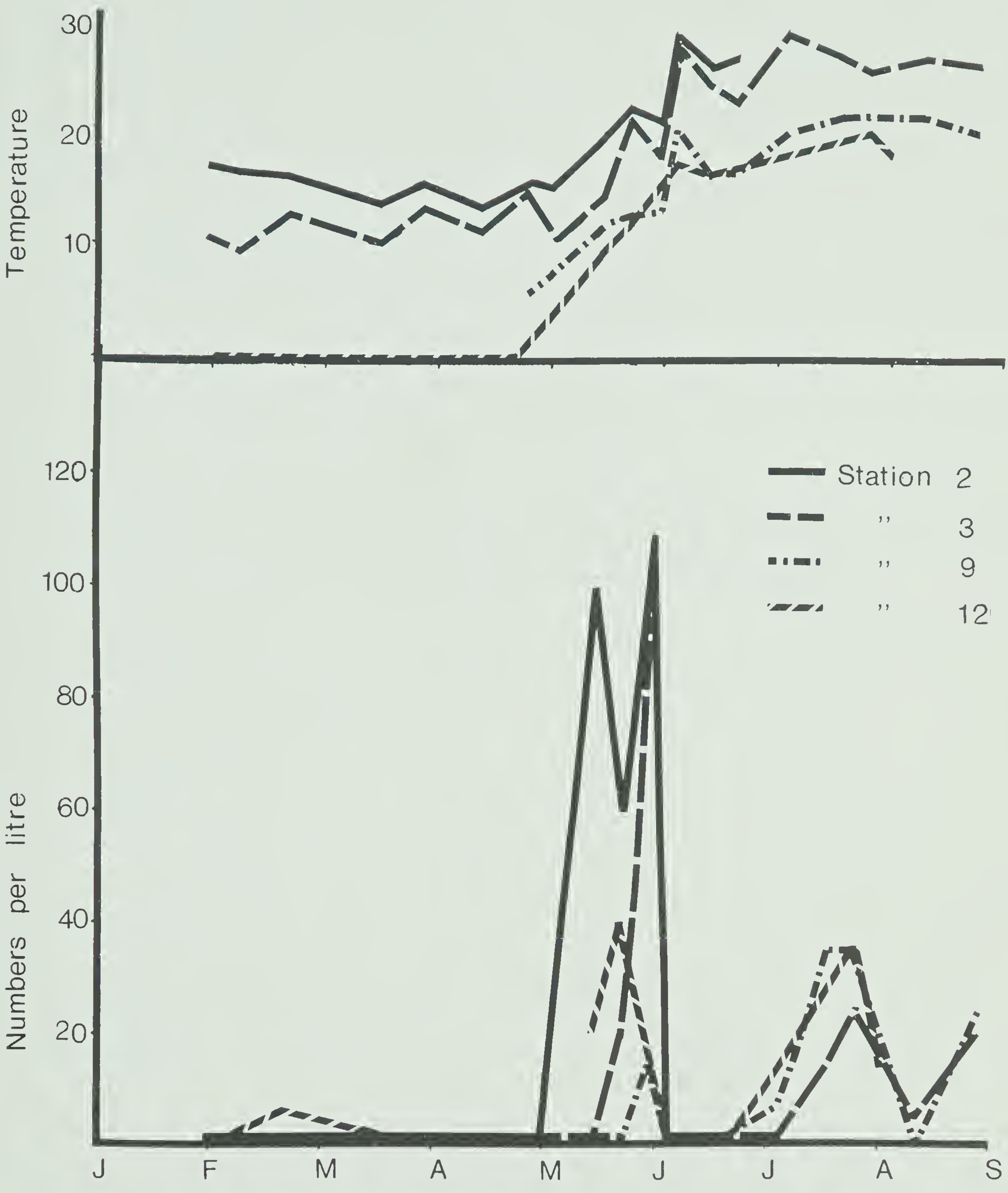
The mean number at station 2 for the summer season (from May 1) was 35.7 females/l. compared to 15.0 females/l. found at station 3, 9.6 females/l. at station 9 and 18.3 females/l. at station 12 during the same period. Annual means were: 17.9 females/l. at station 2, 9.5 females/l. at station 3 and 11.4 females/l. at station 12. These mean differences were not statistically significant.

P. vulgaris occurred at a slightly wider range of temperatures than *N. acuminata* (Figs. 48 and 50) indicating that *P. vulgaris* may be adapted to slightly higher temperatures than *N. acuminata*. A slightly smaller maximum occurred at station 3 than at station 2, with lesser maxima at stations 9 and 12 (Fig. 50).

i. *Conochilus unicornis* Rousselet

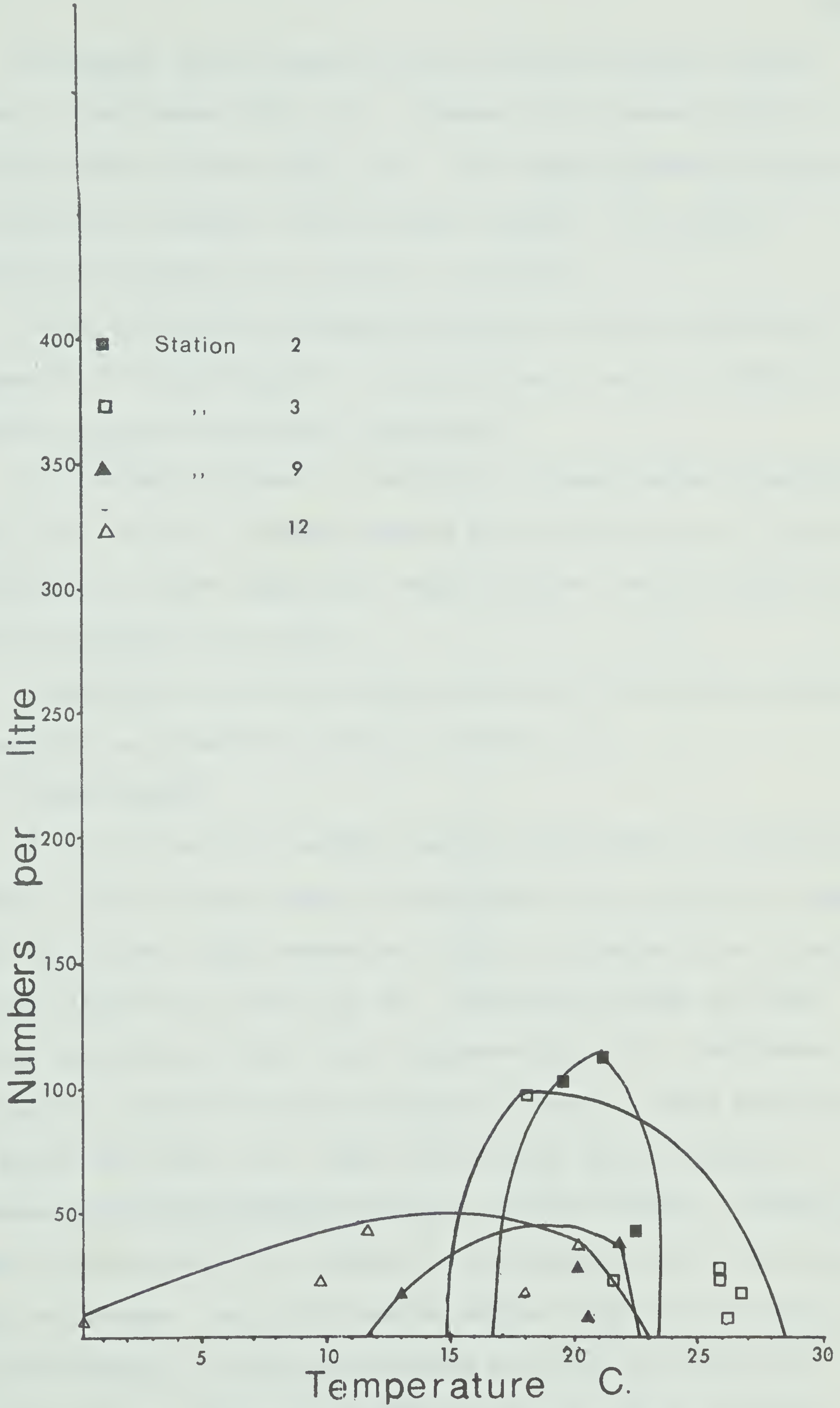
Conochilus unicornis is a colonial species of rotifer. The colony apparently eats food of less than 10 μ in diameter (Naumann, 1923).

Fig. 49. Seasonal changes in temperature (C.), numbers of females of *Polyarthra vulgaris* at stations 2, 3, 9, and 12, 1970.



Temperature
30
20
10
Numbers per litre
120
100
80
60
40
20
Station 2
" 3
" 9
" 12
J
F
M
A
M
J
J
A
S

Fig. 50. Effect of temperature on numbers of adults of *Polyarthra vulgaris* per litre at stations 2, 3, 9, and 12, 1970.


Station 2
,, 3
,, 9
12
400
350
300
250
200
150
100
50
Numbers per litre
5
10
15
20
25
30
Temperature C.

The species did not occur at any of the four stations during winter in Lake Wabamun (Fig. 51). Colonies first appeared on May 14 at each of these stations (Fig. 51). The colonies generally had up to 12 individuals although a few had greater numbers. The species occurred only between May 14 and July 3 (Fig. 51).

During this period the mean at station 2 was 18.6 individuals/l. compared to 7.1 individuals/l. at both stations 9 and 12. These differences were not statistically significant.

C. unicornis occurred at a relatively narrower range of temperatures (9.8 - 25.6 C.). Maximum numbers were found at 11.8 C. (Fig. 52). The relatively narrow temperature range indicates that this species is a warm stenotherm in this lake.

Temperature range for the eggs and adults of these nine species of rotifers are presented in Table 10 and Fig. 53.

j. Other Rotifers

A list of the other rotifers found in Lake Wabamun is presented in Table 11. The six most common of these species were plotted on a graph (Fig. 54).to get a rough comparison of their occurrence in hot (station 3) or cold (station 12) water (Fig. 54). *Gastropus stylifer* was found earlier under the ice than in the open water (Fig. 54). *Trichocerca multicrinis, Colurella* sp. and *Monostyla* sp. were all found earlier in the heated area (Fig. 54). *Lecane* sp. was only found at station 3. *Ploesoma lenticulare* appeared on March 15 at both stations. Samples were taken only until July 31 at station 12 so comparisons after this date could not be made. In all six species numbers found were very small and 7.6 individuals/l. or less were recorded on all but one date (30.0 individuals/l. of *Trichocerca multicrinis* were counted on July 31).

Fig. 51. Seasonal changes in temperature (C.), numbers of individuals of *Conochilus unicornis* at stations 2, 3, 9, and 12, 1970.

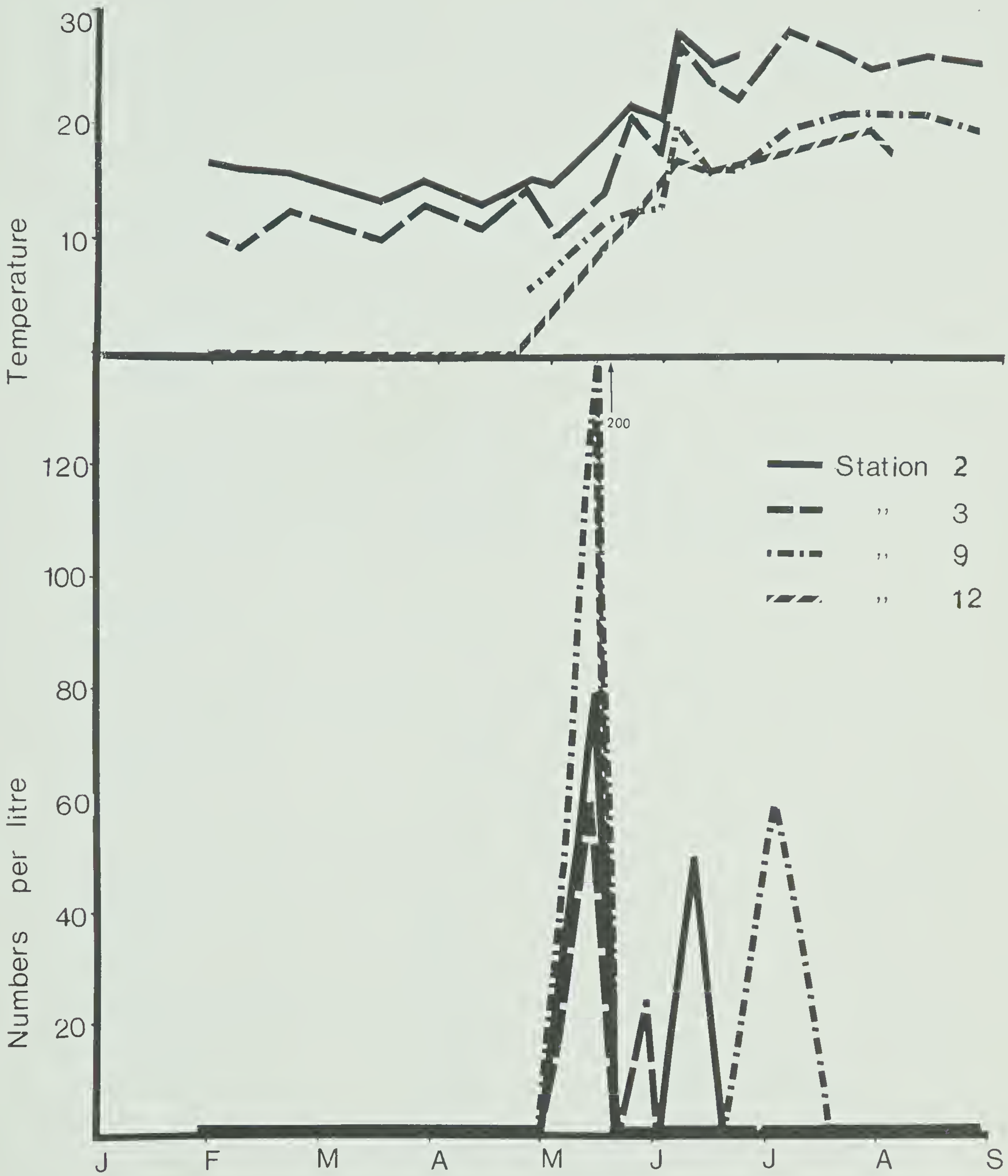
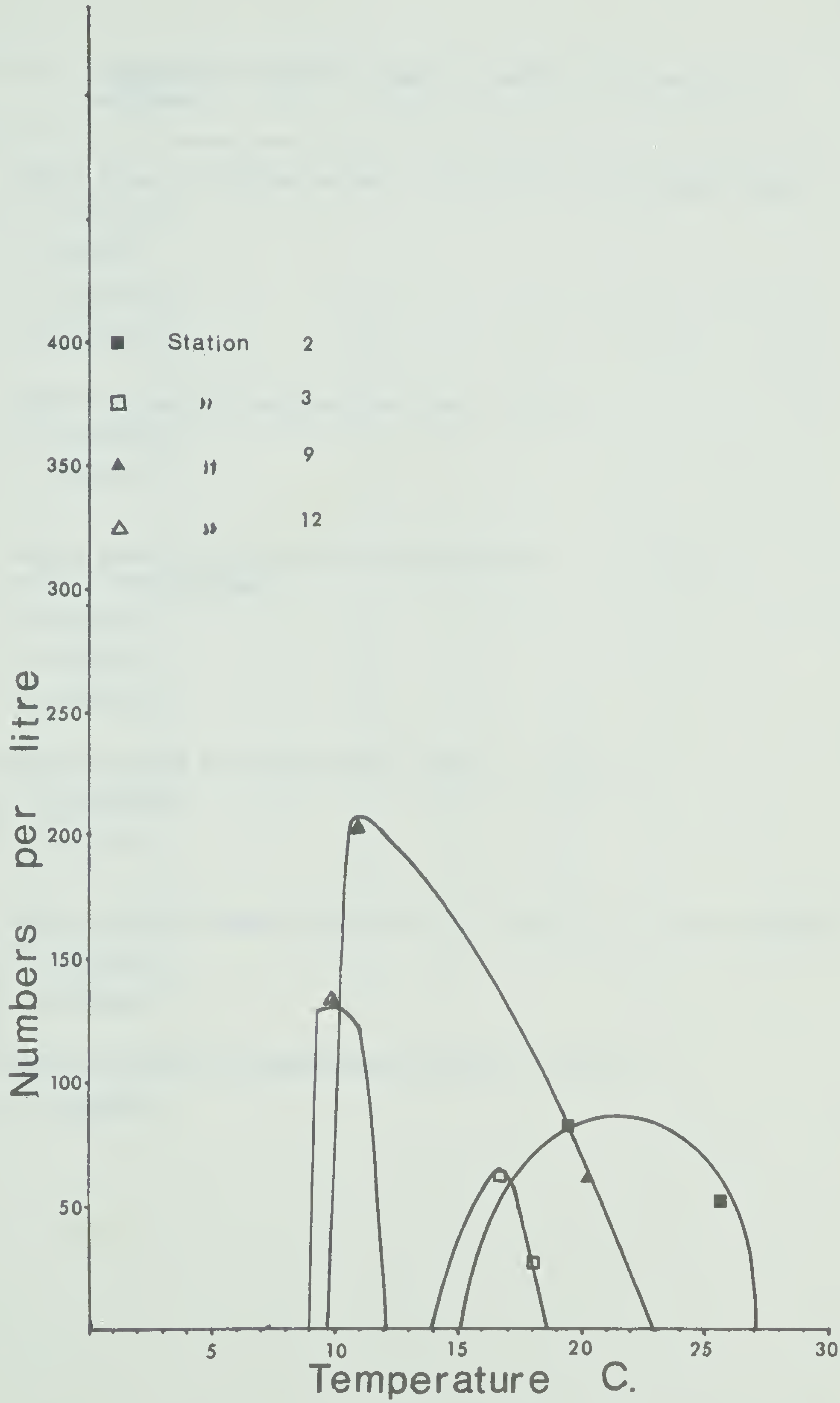

30
20
10
Temperature
200
120
100
80
60
40
20
Numbers per litre
Station 2
,, 3
,, 9
,, 12
J
F
M
A
M
J
J
A
S

Fig. 52. Effect of temperature on numbers of adults of *Conochilus unicornis* per litre at stations 2, 3, 9, and 12, 1970.



Station 2
" 3
" 9
" 12
400
350
300
250
200
150
100
50
Numbers per litre
5
10
15
20
25
30
Temperature C.

Table 10. Temperature range for eggs and adults of 9 species of rotifers.

---

1. Adults found in hottest water - 0 - 29 C. (8 C. above normal)

   K. longispina

   K. hiemalis

   K. cochlearis

   A. priodonta

   Eggs developed at temperatures from 0 - 29 C.

   K. longispina

   K. hiemalis

2. Adults found in intermediate temperatures - 0 - 26.6 C. (6.2 C. above normal)

   K. earlinae

   P. vulgaris

   C. unicornis

   Eggs developed at temperatures from 9.8 - 26.6 C.

   K. cochlearis

   K. earlinae

3. Adults found in temperatures from 0 - 22.4 C. (2 C. above normal)

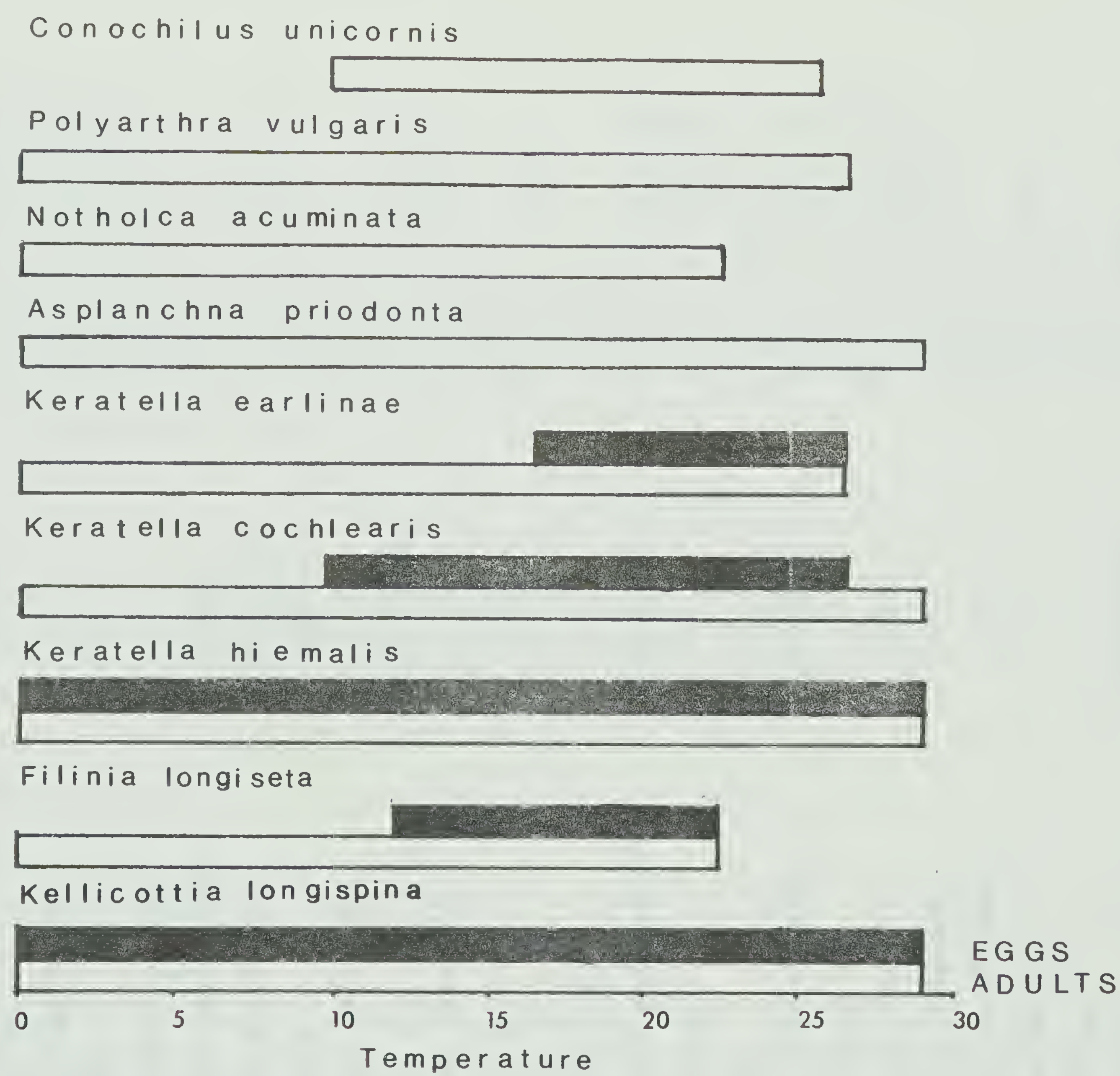
   F. longiseta

   N. acuminata

   Eggs developed at temperatures from 12.0 - 22.4 C.

   F. longiseta

Fig. 53. Temperature range for eggs and adults of nine species of rotifers.



Conochilus unicornis
Polyarthra vulgaris
Notholca acuminata
Asplanchna priodonta
Keratella earlinae
Keratella cochlearis
Keratella hiemalis
Filinia longiseta
Kellicottia longispina
EGGS
ADULTS
0
5
10
15
20
25
30
Temperature

Table 11. Seasonal occurrence of less common rotifers, 1970. (Data compiled from all stations)

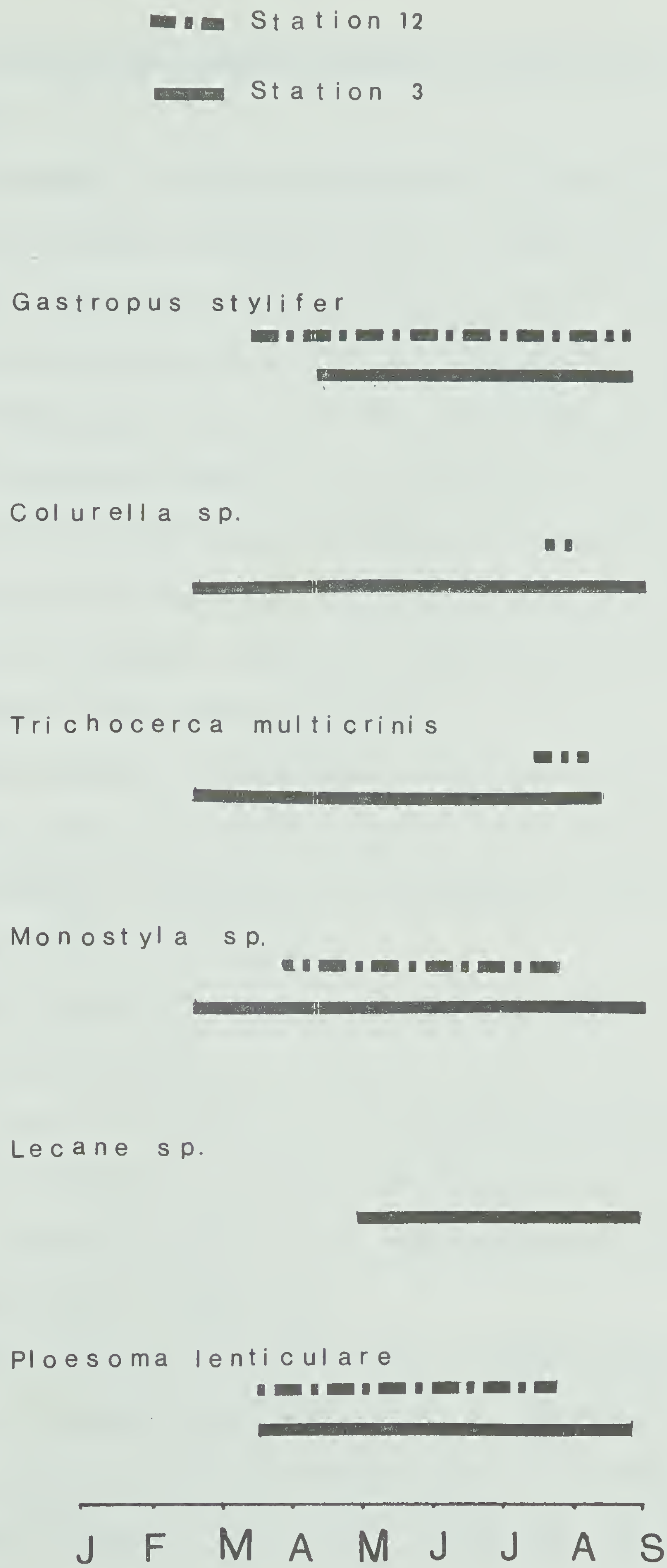
Species	Frequency of Occurrence	Dates of Occurrence
Chromogaster ovalis	infrequent	Jan. 31 - Aug. 10
Euchlanis sp.	"	Jan. 31 - July 17
Ascomorpha saltans?	"	Jan. 31 - May 14
A. ecaudis	"	Jan. 31 - May 29
Polyarthra euryptera	"	Feb. 7 - Aug. 27
Scaridium longicaudum?	rare	Feb. 7
Gastropus stylifer	occasional	Feb. 7 - Aug. 27
G. hyptopus	rare	Feb. 7 - May 14
Collotheca pelagica	"	Feb. 7
Colurella sp.	occasional	Feb. 7 - Aug. 27
Trichotria tetractis	"	Feb. 7 - Aug. 27
Lepadella sp.	rare	Feb. 7
Synchaeta sp.	"	Feb. 7 - May 14
Testudinella sp.	"	Feb. 21
Trichocerca multicrinis	occasional	Feb. 21 - Aug. 27
Monostyla sp.	"	Feb. 21 - Aug. 27
Lecane sp.	"	Feb. - Aug. 27
Ploesoma lenticulare	infrequent	Mar. 15 - Aug. 27
Dipleuchlanis sp.	"	Mar. 15 - July 24
Ascomorpha minima	rare	Mar. 15 - Mar. 26
Trichotria pocillum	"	Mar. 26 - May 21
Mikrocodides chlaena?	"	Mar. 26
Cephalodella sp.	"	Mar. 26 - May 14
Encentrum sp.	"	Mar. 26
Mytilina sp.	infrequent	Mar. - Aug. 10
Trichocerca longiseta	"	Mar. 26 - Aug. 27
Brachionus patulus	"	Mar. 26 - Aug. 10
Conochiloides exiguus?	rare	May 14 - May 21
Epiphanes sp.	"	May 21
Sinantherina sp.	"	May 29

(Cont'd)

Table 11 (Cont'd)

Species	Frequency of Occurrence	Dates of Occurrence
Conochilus hippocrepis	infrequent	June 3 - June 19
Trichocerca dixon-nuttalli	"	July 17 - Aug. 27
Trichocerca porcellus	rare	July 24 - Aug. 10
Ascomorphella volvocicola	"	Aug. 10

Fig. 54. Seasonal occurrence of six less common species of rotifers at stations 3 (heated) and 12 (cool), 1970.



Station 12
Station 3
Gastropus stylifer
Colurella sp.
Trichocerca multicrinis
Monostyla sp.
Lecane sp.
Ploesoma lenticulare
J F M A M J J A S

Because of the small numbers involved it seems unwise to draw any conclusions.

In summary, it might be stated that the heated effluent does in fact have an effect on both the adults and eggs of the rotifer species analysed. Some of the species (see below) failed to produce eggs at temperatures above 22.4 C. A few species were not present as adults at higher temperatures than 22.4 C. Increased temperature also affected rates of population change. In *K. longispina, F. longiseta* and *K. cochlearis* the positive rate of change increased with increase in temperature (Figs. 33, 35 and 42). Temperature increase had the opposite effect on *K. hiemalis*. The rate of change decreased with increase in temperature in this species (Fig. 39).

The influence of temperature on the nine species can be divided into three groups depending on whether or not the species can survive the full range of temperature, an intermediate range or a narrow temperature range (Fig. 53; Table 10).

1. Four species of rotifers are seemingly adapted to the complete temperature range found in the lake (0 - 29 C.) (Fig. 53, Table 10). However, only *K. longispina* and *K. hiemalis* produced eggs over the same temperature range and, therefore, are the only two (of nine analysed) species completely adapted to the whole temperature range as both eggs and adults (Fig. 53, Table 10).

2. Three species may be placed into a second category which contains adults to a maximum temperature of 26.6 C. Two species produced eggs to this maximum and in one of these species *(K. cochlearis)* the adults seemingly tolerated a wider range of temperature than the eggs (Fig. 53, Table 10).

3. The third temperature range contained two species which were found in waters only up to 22.4 C. (2.0 C. higher than the normal maximum lake temperature). It is quite possible that these two species have not adapted to water heated above the normal summer maximum in a lake, though the 22.4 C. limit at which the species were found could possibly be reached in a very warm summer in an unaffected lake.

Because all of the rotifer species survived temperatures up to 22.4 C. or higher it might be reasonable to consider temperatures in excess of 22.4 C. as thermally polluting in Lake Wabamun. Hence, a definition for thermal pollution (for rotifers) in this lake might be "the heating of lake water in excess of 22.4 C." However, this definition might only be acceptable for the summer season because normal lake temperatures are much cooler at other seasons.

Surface Samples

From June 6 to October 19, 1969, a neuston sampler modified from the design of David (1965) (Plates 1 and 2) was towed for 100 m. in the inlet and outlet canals and at station 12. To make a direct comparison of fauna between the three areas a correction had to be made for the greater volume of water passing through the net in the two canals. During a 100 m. tow in the canals it was found that a volume of water 1.5 (approx.) times greater passed through the net than in the open water, assuming that the latter is motionless or very nearly so. Therefore, $\frac{N}{1.5}$ was the correction factor used where N was the number of organisms passing through the net in a 100 m. tow in the canals.

The fauna from each of the different areas was then compared to discover whether the widely different temperatures in the area affected

the surface fauna. It would seem likely that turbulence caused by currents in the canals would dislodge some of the organisms at the air-water or water-air interfaces. However, the net sampled the top 8 cm. in each of the areas and comparisons were made after the correction was applied. Slight variation from the 1.5 probably occurred but for qualitative comparisons it seems reasonable to use this figure.

a. *Protista*

To get some idea what protistans were present living samples were examined immediately on return from the field to the laboratory. At least 60 species were identified using mainly Kudo's (1966) and Jahn's (1949) keys. Taking *Ceratium hirundinella* as a typical unicellular organism a comparison was made of its seasonal distribution in the three areas.

Greatest numbers occurred in each area on July 4, 1969 (Table 12). The mode occurred almost a year later (in the pump samples) on July 10, 1970 (Fig. 29). The temperature at Sundance on that date was 15.5 C. and this may be compared to the temperature of 14.4 C. at which Findenegg (1943) found this species in greatest numbers in some of the Corinthian lakes.

Of these three areas the mean number in the outlet canal was 11151 individuals/m.^{3} higher than the 8003 individuals/m.^{3} in the inlet canal and only 5856 individuals/m.^{3} in the open lake at Sundance. It should be kept in mind that the inlet canal mouth is comparable to a funnel drawing organisms from the lake and concentrating them in a smaller area. The planktonic organisms are unlikely to overcome the currents and escape. It is more difficult to explain the even greater number of specimens in the warmest area, i.e, the outlet canal. It was stated in an earlier section that *C. hirundinella* tends to avoid the stations near the outlet

Table 12. Comparison of selected species from surface samples taken by neuston net from outlet and inlet canals and Sundance, 1969.

Species	Date	Site		
		Inlet	Outlet	Sundance
		Numbers per m.^{3}		
Ceratium hirundinella	June 6	133	1067	-
	" 20	2833	8977	-
	July 4	34983	53437	23466
	" 18	9155	4755	2800
	Aug. 1	4888	6390	266
	" 15	3421	3555	4866
	" 26	6468	6133	2132
	Sept. 13	17067	14488	5332
	" 28	889	1555	2132
	Oct. 19	195	-	-
Keratella cochlearis	June 6	12888	10933	-
	" 20	1833	11555	-
	July 4	2602	4445	6200
	" 18	2356	2177	7932
	Aug. 1	6888	6222	9400
	" 15	1333	1911	20200
	" 26	641	1911	1666
	Sept. 13	1155	1200	1600
	" 28	-	355	932
	Oct. 19	2221	-	-
Keratella hiemalis	June 6	311	177	-
	" 20	44	88	-
	July 4	0	0	0
	" 18	0	0	0
	Aug. 1	0	0	0
	" 15	0	0	66
	" 26	0	0	0
	Sept. 13	0	0	0
	" 28	0	0	132
	Oct. 19	0	0	0
Kellicottia longispina	June 6	2043	1421	-
	" 20	567	1955	-
	July 4	0	157	0
	" 18	0	0	0
	Aug. 1	0	0	0
	" 15	0	0	0
	" 26	98	0	0
	Sept. 13	0	0	0
	" 28	0	0	0
	Oct. 19	97	0	0

canal because of the heated water, but it seems unlikely that it can avoid getting into the canals because of the currents. However, the organism may not survive in the warmer water because if it did then it would have been more prevalent at stations 1 - 7.

b. *Rotifera*

No eggs were counted when analysing the neuston rotifers but a numerical comparison was made similar to the one for *C. hirundinella*. Of the four most common species (*Kellicottia longispina, Keratella cochlearis, Keratella hiemalis* and *Filinia longiseta*) described in detail in the previous section, one was completely absent from the three areas (*Filinia longiseta*). This was surprising considering the fact that it is regarded as a summer species (already mentioned). However, even with the pump samples the following summer it occurred in low numbers and a possible explanation was given in that section. The other three species are treated here.

Keratella cochlearis was the most abundant species during the summer of 1969 (Table 12). This species was most abundant at Sundance (mean 6847 individuals/m.^{3}), with lower numbers in the outlet canal (mean 4523 individuals/m.^{3}) and a mean of only 3546 individuals/m.^{3} in the inlet canal. It is significant to note that on August 15 only 1911 individuals/m.^{3} were found in the outlet canal (temperature 31.8 C.), 1333 individuals/m.^{3} in the inlet (temperature 27.1 C.) and 20200 individuals/m.^{3} at Sundance. The extremely high temperatures in the canals on this date appeared to be very unsuitable to the rotifer and it obviously attempted to avoid the area but currents probably managed to channel the animals found towards the inlet canal. Considering the possible effect of con-

centration by funneling organisms into the canal the tremendous numerical difference between the areas is very significant.

Kellicottia longispina was found only up to July 4 in the outlet canal (Table 12) but also on two later dates in the inlet canal. The species was not found at Sundance at all. However, there is no reason to suspect that it was confined to the canals. A mean of 392.6 individuals/$m.^3$ was recorded for the outlet canal compared to the mean of 280.5 individuals/$m.^3$ in the inlet canal.

Keratella hiemalis was found in small numbers during the same period at all three areas. The mean of 35.5 individuals/$m.^3$ occurred in the inlet canal with fewer (mean of 29.4 individuals/$m.^3$) in the outlet canal and fewest (mean of 22.0 individuals/$m.^3$) at Sundance. No temperature effect could be noticed here because of the small numbers.

Of the 22 species of rotifers found at Sundance only *Ploesoma lenticulare* and *Cupelopagis vorax?* were not found in either of the canals. However, both of these species were only found on one occasion each. Similarly, a few species occurred sporadically in one or the other of the canals and not at Sundance but this could not be considered significant.

Bottom Fauna

Bottom samples were collected regularly at stations 4 and 13 from June 26, 1968 to August 26, 1969. At least one Ekman dredge sample was collected from each of these areas on each sampling date and analysed (Appendix X).

DISCUSSION

On page 124 a workable definition of thermal pollution was given which took the summer maximum temperature into account. Using this definition, the north-east end of Lake Wabamun was considered to be thermally polluted much of the time during the study season.

Lake Wabamun is considered eutrophic as mentioned in the Introduction. Changes in the lake ecosystem brought about by the thermal effluent are complex.

Although as mentioned the heated water is generally confined to the shallow north-east end of the lake, it should be kept in mind that this area varied with the direction and velocity of the prevailing winds and currents. On calm days, warmer water being less dense floats as a plume on top of the cooler lake water. During windy weather this plume is mixed with the normal lake water and no density gradient occurs under such conditions. Temperature differences and fluctuations caused by the addition of a thermal effluent to the north-east end of the lake have been described in detail in the physical section of this thesis.

The heated area being unfrozen at any time during winter exists as an open system; whereas, the remainder of the lake is a closed system for this six month period and hence the latter area is similar to the other lakes in this region (Nursall, 1969). Because of the lack of an ice cover in the heated area there are some differences besides temperature between this region and the unaffected lake and these are described below.

Turbidity is slightly higher at the warmer station 4 (Fig. 7, Table 3) than at the cooler station 13. During winter, light intensity

differences were great between station 4 and 13 (Figs. 8 and 9). Under the ice at station 13 only 5.7% of the visible light actually penetrated through the thick covering of snow and ice (Fig. 9). On the same date (April 9) 100% of the visible light reached the unfrozen water surface at station 4 in the heated area. During summer (July 8) differences in light intensities were lower at both stations than at station 4 in winter because of the presence of a more abundant summer phytoplankton population.

During winter dissolved oxygen concentrations differed widely at stations 4 and 13 (Table 7, Figs. 25 and 26). At station 4 the water surface is constantly exposed to the air and this fact, together with the currents, keeps the warmer water more aerated than the cooler ice-covered normal lake water (Table 7, Figs. 25 and 26). Oxygen is not replenished at station 13 because of the snow and ice. The concentration declined at station 13 during winter until a saturation of only 4% was recorded at a depth of 9.75 m. on two dates during March 1969 (Table 7, Fig. 25). Comparing the top two meters of the water column during winter at both stations it was found that saturation fell to 49% at station 13 and 63% at station 4 (Table 7).

During the rest of the year differences in oxygen concentration between the two stations were less. In general, surface oxygen concentrations were slightly higher at station 4 than at station 13, perhaps because of the photosynthetic activity of the macrophytes and replenishment of oxygen by currents (Table 7, Figs. 25 and 26). At a depth of two meters the oxygen was usually slightly higher at station 13 than at station 4 during this period.

Some differences occurred in phytoplankton between the warm and cold water. Examining Figures 27 and 28 of Wheelock (1969) it is worth-

while mentioning that a number of the species appeared earlier in spring at station 4 than at station 13 (stations 1 and 2 of Wheelock).

Macrophyte vegetation may also have a longer growing season in open water. Observations in winter suggest that some species were green and evidently photosynthesizing in the heated area while under the ice the plants were generally brown and seemingly non-functional. This longer growing season could contribute to increasing the weed production of the lake in the heated zone but whether or not temperature increased the rate of growth is not known. Even if temperature did not speed up growth processes, the extended growing season might increase the weed problem in the area.

Examining the effects of thermal pollution on the zooplankton, the rotifers were studied in greatest detail. Other workers are analysing the effects of temperature on the crustaceans and this group will not be discussed here.

Edmondson (1960) has shown that water temperature influences the reproductive rate of rotifers. At higher temperatures (but not above normal lake temperatures), rates of reproduction are faster and life cycles are shorter (Edmondson, 1960; Hutchinson, 1967). However, these authors did not mention the possible effects, on reproduction and life cycles, of raising water temperatures several degrees above the normal.

Data for Lake Wabamun have shown that temperatures in excess of 22.4 C. (2.0 C. above maximum normal lake temperature) have detrimental effects on at least two species of rotifers (Fig. 53, Table 10). Adult females and eggs of *F. longiseta,* normally a summer species (Hutchinson, 1967; Pejler, 1965), were never found at temperatures greater than 22.4 C. Also, the species had become a spring rather than a summer species in the

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lake (Figs. 34 - 36). The second rotifer which apparently could not tolerate temperatures above 22.4 C. was *N. acuminata*, a cold stenotherm (Carlin, 1943).

The other seven common species of rotifers were found in water warmer than 22.4 C. and exhibited varying degrees of adaptation to the heated effluent (Fig. 53, Table 10). The colonial species *C. unicornis*, which was found only in the summer, behaved as a warm stenotherm in the lake being found in temperatures varying from 9.8 to 25.6 C. (Fig. 53, Table 10). *K. earlinae* was found in temperatures to a maximum of 26.5 C. Eggs were found only on specimens at temperatures in excess of 16.5 C. *P. vulgaris*, a eurythermal species (Pejler, 1956), was found in waters up to a maximum of 26.6 C. Adults of *K. cochlearis* were found at all temperatures recorded at the four stations studied in depth (0 - 29 C., Figs. 40 and 41, Table 10). However, eggs of this species occurred only in water warmer than 9.8 C. and cooler than 26.6 C. and this would suggest egg production is quite temperature sensitive in *K. cochlearis*. The carnivore *A. priodonta* was found at the complete temperature range, suggesting that it is eurythermal. Eggs and adults of *K. longispina* and *K. hiemalis* also appeared to survive the 29 C. temperature range. *K. hiemalis* was described by Pejler (1957) as a cold tolerant stenotherm but in this lake it is obviously a eurytherm although it prefers cooler water.

As well as mentioning the effects of increased temperature on the rotifer species it is perhaps important to consider the effect of low temperatures on egg production (Fig. 53). As mentioned above, three of the five species analysed for egg production did not carry eggs in cooler water (Fig. 53). It is possible that these species would not be present in the lake, or at least would not reproduce, if heated water had not been

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present in winter. During winter *K. cochlearis* only produced eggs at the warmer stations 2 and 3 and did not produce eggs in the unaffected lake until the temperature reached 9.8 C. (Figs. 40 and 41). *F. longiseta* did not produce eggs during winter in normal lake water until the temperature reached 12.0 C. in spring (Figs. 40 and 41). Similarly, *K. earlinae* did not reproduce until the temperature was 16.5 C. and in fact eggs were only found in the normal (station 12) lake on only one occasion at the end of July compared to three periods of egg production at the two warmer stations (Fig. 43).

Floscularia conifera, a colonial rotifer studied by Edmondson (1946), did not feed or lay eggs when transferred from temperatures of 18 - 20 C. to water at 10 C. Perhaps in Lake Wabamun a similar effect is produced in winter on the three species above (and perhaps others) when a rotifer drifts from temperatures of 9.8 C. (coolest temperature recorded at station 3) or higher to temperatures from 0 to 4 C. (normal winter lake temperatures). From this evidence it is possible to conclude that these three species, and perhaps others, would not be present in the lake in winter were it not for the addition of heated water.

The fact that eggs are produced earlier in the heated zone suggests that this part of Lake Wabamun is more productive than the normal lake.

It could also be argued that this is also evidence that the life cycles are speeded up. This apparent increase in production might also be enhanced by the extended season of growth in spring and fall for some of the rotifer food (e.g., phytoplankton mentioned above). The acceleration of life cycles and increased production caused by the presence of heated water would in turn be affecting the natural rate of

eutrophication in the lake.

If the operation of a second thermal power plant on Lake Wabamun (opened late 1970) produces similar effects to the first one, the combined influences of the two effluents may perhaps accelerate eutrophication. In a time when recreational demands are a prime consideration it would seem unwise to speed up the death of this much favoured body of water.

SUMMARY AND CONCLUSIONS

1. An ecological study was carried out on some of the chemical, physical and biological effects of the heated water (from a thermal power plant) on the eutrophic Lake Wabamun, Alberta.

2. The lake has a surface area of 32.5 km.^{2}. About 5% of the lake surface receives heated water. The lake is shallow, having a maximum depth of 11.6 m.

3. On calm days the warmer, less dense, effluent floats as a plume on top of the cooler denser lake water. The effect of this is to produce a thermocline about 0.5 - 1.0 m. below the surface of the water. On very windy days the thermocline is broken down and complete mixing occurs, distributing the heat evenly.

4. During winter the heated area remains ice-free. The shape and extent of this zone depends upon the strength and direction of the prevailing winds.

5. In winter 100% of the incident light reaches the surface of the heated ice-free water. In late winter (April 9) only 5.7% of the incident light actually penetrates the snow-ice cover.

6. Winter oxygen concentrations in the heated area are generally higher than under the ice because of exposure to the air (by wind action), and turbulence from water flowing out of the outlet canal.

7. Turbidity is slightly higher in the heated zone than in the normal lake but this could be attributed to the effect of exposure to wind, particularly during winter when an ice cover is absent.

8. Maximum normal lake temperatures did not exceed 20.4 C. during the study period compared to a 29.0 C. temperature recorded at one of the sampling stations (2) in the warmer water. A maximum temperature of 31.8 C. was recorded in the outlet canal.

9. At least one phytoplankton species, *Ceratium hirundinella,* was found to show preference for slightly elevated temperatures (e.g., near the outlet) but least preference for the warmest water. Optimum numbers were found at 21.9 C.

10. A total of 47 species of rotifers was found in the lake. Nine of the most common ones were analysed for temperature effects upon both adult populations and egg production.

11. *Kellicottia longispina* and *Keratella hiemalis* were the only two (of nine) species that survived, as eggs and adults, a temperature range from 0 - 29 C.

12. The carnivore *Asplanchna priodonta* survived the same temperature range of 0 - 29 C. This species produced live young.

13. Adults of *Keratella cochlearis* survived the 0 - 29 C. temperature range but egg production only occurred between 9.8 - 26.6 C.

14. Adults of *Polyarthra vulgaris* were found in the 0 - 26.6 C. range. Eggs were rarely seen and hence their temperature range could not

be determined.

15. Adults of *Keratella earlinae* survived at temperatures from 0 - 26.5 C. but eggs were produced only from 16.5 - 26.5 C.

16. The colonial species *Conochilus unicornis* survived temperatures from 9.8 - 25.6 C.

17. *Notholca acuminata* and *Filinia longiseta* both survived temperatures from 0 - 22.4 C. Eggs of *F. longiseta* were found only between 12.0 - 22.4 C. Eggs of *N. acuminata* were rarely seen.

18. All rotifers survived temperatures up to 22.4 C. and temperatures in excess of this were detrimental to at least some rotifers.

19. Effects of temperature change on the rate of change of populations (%/day) were examined for the four most common species of rotifers.

20. Three species, *Kellicottia longispina*, *Filinia longiseta* and *Keratella cochlearis* showed an increased positive rate of population change with increased temperature.

21. In one species, *Keratella hiemalis*, the rate of change of population decreased with increased temperature.

LITERATURE CITED

Ahlstrom, E.H. 1943. A revision of the rotatorian genus *Keratella* with descriptions of three new species and five new varieties. Bull. Amer. Mus. Nat. Hist., Vol. LXXX, Article XII, 411-457.

Amrén, H. 1964. Ecological and taxonomical studies on zooplankton from Spitsbergen. Zoologiska Bidrag Fran Uppsala, Band 36, 210-276.

Anderson, R.S. 1970. Physical and chemical limnology of two mountain lakes in Banff National Park, Alberta. J. Fish. Res. Bd. Canada, 27:233-249.

Anonymous. 1967. Annual meteorological summary. Meteorological Branch, Dept. of Transport, Canada.

Arnol'd-Aliab'ev, V.I. 1933. The chemical nature of ice in the Gulf of Finland as based on its strength. Ivestija Instuta Obshchey i Neorganicheskoy Khmii, 6:229-233. (Abstract in S.I.P.R.E. Bibliography.)

Bennington, K.O. 1967. Desalination features in natural sea ice. J. Glaciology, 6:845-857.

Brinkhurst, R.O., A.L. Hamilton, and H.B. Herrington. 1968. Components of the bottom fauna of the St. Lawrence, Great Lakes. Great Lakes Institute, University of Toronto, March 1968, No. Pr. 33, 49 pp.

Carefoot, J.R. 1959. A preliminary survey of the algae of the Edmonton region of Alberta. M.Sc. Thesis, University of Alberta, 95 pp.

Carlin, B. 1943. Die Planktonrotatorien Des Motalström, zur Taxonomie Ökologie der Planktonrotatorien. Meddelanden Fran Lunds Universitets Limnologiska Institution, N:R5, 255 pp.

Chalupa, J. 1959. Limnological study of the reservoir Sedlice near Želiv. III Chemical part : Iron and dissolved inorganic phosphates. In: Scientific Papers from Institute of Chemical Technology, Prague. Faculty of Technology of Fuel and Water, 3, part 2, p.1-166.

Clark, J.R. 1969. Thermal Pollution and Aquatic Life. Scientific American 220 (3), 18-27.

Clarke, G.L. 1939. The utilisation of solar energy by aquatic organisms. Prob. Lake Biology, A.A.A.S.Publ., 10:27-38.

Daborn, G.R. 1969. Transient ecological succession in a shallow pond. M.Sc. Thesis, University of Alberta, 104 pp.

David, P.M. 1965. The neuston net: Device for sampling surface fauna. Journ. Mar. Biol. Assoc. U.K. 45(2), 313-320.

Edmondson, W.T. 1946. Factors in the dynamics of rotifer populations. Ecol. Monog., 16:357-372.

_____________ 1957. Trophic relations of the zooplankton. Trans. Amer. Micr. Soc. LXXVI, 3:225-245.

_____________ 1960. Reproductive rates of rotifers in natural populations. Mem. Ist. ital. Idrobiol. de Marchi 12 (1960): 21-77.

_____________ 1965. Reproductive rate of planktonic rotifers as related to food and temperature in nature. Ecol. Monog., 35:1, 61-111.

Einsele, W. 1941. Die Umsetzung von zugeführtem, anorganischem Phosphat im eutrophen See und ihre Rückwirkung auf seinen Gesamthaushalt, Z. f. Fischerei 39, 407-488.

Findenegg, I. 1943. Unterschungen über die Ökologie und die Produktionsverhältnisse des Planktons im Kärntner Seegebiete. Internat. Rev. ges. Hydrobiol. Hydrogr., 43, 368-429.

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Greenbank, J.T. 1945. Limnological conditions in ice-covered lakes, especially as related to winter-kill of fish. Ecol. Monog. 15(1): 345-390.

Hamilton, A.L. 1969. Keys to identification of larval and pupal Chironomidae. Unpublished Manuscript, 61 pp.

Harvey, H.W. 1937. The supply if iron to diatoms. J. Mar. Biol. Ass. U.K., 22:205-219.

Höll, K. 1928. Oekologie der Peridineen-Studien über den Einfluss chemischer und physikalischer Faktoren auf die Verbreitung der Dinoflagellaten im Süsswasser. Pflanzenforschung, 11, vi, 105 pp.

Hutchinson, G.E. 1957. A treatise on limnology. Vol. 1 Geography, Physics and Chemistry. Wiley and Sons, 1015 pp.

______________ 1967. A treatise on limnology. Vol. II Introduction to Lake Biology and the Limnoplankton. Wiley and Sons, 1115 pp.

Hynes, H.B.N. 1966. The Biology of Polluted Waters. Liverpool University Press, 202 pp.

Ivlev, V.S. 1937. Material zur Studium der Stoffbilanz im See. Die Eisenbilanz. Arb. limnol. Sta. Kossino, 21:Russ. text, 21-53, Germ. summ., 54-59.

Jahn, 1949. How to know the Protozoa. Wm. C. Brown Co. Pub. 234 pp.

Järnefelt, H. 1956. Zur Limnologie einiger Gewässer Finnslands. XVI. Mit besonderer Berücksichtigung des Planktons. Suomal. eläin-ja kasirt. Sevr. van. eläin. Julk. (Annls Zool. Soc. Vanamo), 17, No. 7: 201 pp.

Kendrew, W.G., and B.W. Currie. 1955. The Climate of Central Canada. Ottawa, Queen's Printer, 194 pp.

Kérekes, J. 1965. A comparative limnological study of five lakes in Central Alberta. M.Sc. Thesis, University of Alberta, 164 pp.

Kudo, R.R. 1966. Protozoology. Charles C. Thomas, Pub. Springfield, Ill., U.S.A., 1174 pp.

Lefèvre, M. 1942. L'Utilization des Algues d'eau douce par les Cladocera. Biol. de la France et Bèlgique.

Moss, E.H. 1932. The vegetation of Alberta. IV the Poplar association and related vegetation of Central Alberta. Jour. Ecol. 20:380-415.

__________ 1955. The vegetation of Alberta. Bot. Rev. 21:394-567.

__________ 1967. Flora of Alberta. University of Toronto Press, 546 pp.

Naumann, E. 1923. Spezielle Unterschungen über die Ernährungsbiologie des tierschen Limnoplanktons. II Uber den Nahrungserwerb und die natürliche Nahrung der Copepoden und die Rotiforen des Limnoplanktons. Lunds Univ. Arsskr. n.f., 19, 3-17.

Nauwerck, A. 1963. Die Beziehungen zwischen Zooplankton und Phytoplankton im See Erken. Symbolae Botanicae Upsala, 17, 5:1-162.

Nursall, J.R. 1969. The general analysis of a eutrophic system. Verh. Internat. Verein. Limnol. 17:109-115, Stuttgert, Nov. 1969.

Nursall, J.R. and M.E. Pinsent. 1969. Aggregations of spottail shiners and yellow perch. J. Fish. Res. Bd. Canada 26:1672-1676.

Nygaard, G. 1949. Hydrobiological studies of some Danish ponds and lakes II. (K. danske Vidensk. Selsk.). Biol. Skr., 7, 293 pp.

Pearsall, W.H. 1932. Phytoplankton in the English Lakes. II The composition of the phytoplankton in relation to dissolved substances. J. Ecol. 10:241-262.

Pejler, B. 1956. Introgression in planktonic Rotatoria with some points

of view on its causes and conceivable results. Evolution, Vol.X, (3), Sept. 1956, 246-261.

______________ 1957. Taxonomic and ecological studies on planktonic Rotatoria from North Swedish Lapland. Kungliga Svenska Vetenskapsakademiens Handlingar. Fjarde Serien. Band 6. Nr. 57, 68 pp.

______________ 1962. On the variation of the rotifer *Keratella cochlearis* (Gosse). Zool. Bidrag Frän Uppsala. Band 35, pp. 1-17.

______________ 1965. Regional-ecological studies of Swedish fresh-water zooplankton. Zoologiska Bidrag Fran Uppsala Band 36: 4,408-415.

Pennak, R.W. 1953. Fresh-water invertebrates of the United States. Ronald Press Company, New York, 769 pp.

Pinsent, M.E. 1967. A comparative limnological study of Lac La Biche. M.Sc. Thesis, University of Alberta, 149 pp.

Rodhe, W. 1955. Can plankton production proceed during winter darkness in subarctic lakes? Verh. Internat. Verein. Limnol. 12:117-122.

Rutherford, R.L. 1928. Geology of the area between the North Saskatchewan and McLeod Rivers, Alberta. Res. Council Alberta Rept. 19, 42 pp.

Ruttner, F. 1937. Ökotypen mit verschiedener Vertikalverteilung in Plankton der Alpenseen. Int. Revue ges. Hydrobiol. Hydrogr., 35: 7-34.

______________ 1963. Fundamentals of limnology. University of Toronto Press, 295 pp.

Welch, P.S. 1948. Limnological Methods. McGraw-Hill Book Co., Inc., New York, 381 pp.

Wheelock, J.M. 1969. Phytoplankton ecology in Wabamun Lake and the effect of thermal pollution. M.Sc. Thesis, University of Alberta, 178 pp.

Wiese, W. 1930. The salts contained in sea ice. Ann. Hydrographic u. Maritim. Meteorology, 58: 282-286. (Abstract in S.I.P.R.E. Bibliography.)

Williams, L.G. 1966. Dominant planktonic rotifers of major waterways of the United States. Limnology and Oceanography, 11(1):83-91.

Wyatt, F.A., J.D. Newton and T.H. Mather. 1930. Soil survey of St. Ann Sheet. University of Alberta. College of Agriculture. Bull. 20: 66 pp.

A P P E N D I C E S

APPENDIX I

Specific Conductance at Stations 4 and 13, in micromhos and p.p.m., 1968-1969.

Year	Date	Station 4		Station 13	
		micromhos	p.p.m.	micromhos	p.p.m.
1968	July 7	385	215.6	380	212.8
	Aug. 8	380	212.8	---	---
	" 20	395	221.2	---	---
	Sept. 27	---	---	580	324.8
	Oct. 10	405	226.8	410	229.6
	" 30	410	229.6	400	224.0
	Nov. 22	405	226.8	---	---
1969	Feb. 5	460	257.6	240	134.4
	" 19	480	268.8	---	---
	Mar. 8	370	207.2	460	257.6
	" 26	460	257.6	460	257.6
	Apr. 9	460	257.6	380	212.8
	" 28	420	235.2	420	235.2
	May 6	400	224.0	420	235.2
	" 13	420	235.2	---	---

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APPENDIX II

Some Chemical Characteristics of Surface Water

at Stations 4 and 13

1968-1969

APPENDIX II

Year	Date	Station	Iron	Ortho-Phosphate	Total Phosphate	Nitrite Nitrogen	Nitrate Nitrogen	Silica	Sulphate	Manganese	Copper	Fluoride	Fluorine	Chloride	Chlorine
1968	Feb. 15	4	.13	.15	---	0	0	4.5	43	0.5	.10	---	---	7.5	.01
		13	---	---	---	---	---	---	---	---	---	---	---	---	---
	May 22	4	.06	.10	---	0	0	3.2	5	0.3	.12	.27	.32	7.5	.01
		13	.08	.10	---	0	0	4.3	23	.12	.12	.27	---	7.5	.01
	June 11	4	.10	.22	---	0	0	2.4	158	0	.10	.34	---	5.0	.01
		13	.02	.18	---	0	0	2.4	395	0	.09	.20	---	5.0	.01
	" 18	4	.12	.10	---	.01	↓	2.3	24	0.1	.10	---	---	7.5	.01
		13	.02	.15	---	.01		2.1	---	.25	.10	---	---	8.5	.01
	" 26	4	.08	.21	---	.01	a	2.9	8	1.3	.10	---	.83	5.0	.01
		13	.10	.38	---	.01	d	2.5	15	.75	.07	---	---	6.0	.01
	July 3	4	.08	.10	---	.01		2.0	29	1.3	.18	---	.30	4.0	.02
		13	.08	.10	---	.01		1.6	27	1.25	.11	---	.70	5.0	.01
	" 9	4	.03	.15	---	.01	i	1.4	11	2.0	.12	---	.49	9.0	.02
		13	.02	.08	---	.01	n f	1.4	5	2.10	.13	---	.40	7.5	.02
	" 16	4	.13	.30	---	.01	i	1.6	22	1.8	.07	---	.36	7.5	.02
		13	.08	.30	---	0	n	2.5	19	1.75	.10	---	.35	7.5	.02
	" 23	4	.16	.31	---	0	i	1.4	26	1.7	.09	---	.36	5.5	.01
		13	.08	.28	---	0	t u	2.7	19	1.80	.08	---	.32	5.0	.02
	" 31	4	.29	.10	---	0	m	---	34	1.3	.06	.23	.39	6.0	.01
		13	.10	.25	---	0		2.2	276	.90	.04	.30	.50	5.0	.02
	Aug. 6	4	.48	.20	---	0	↓	1.7	208	1.0	.09	.27	.38	4.5	.01
		13	---	.25	---	0		2.9	1088	.45	.07	1.34	.44	5.0	.02

(Cont'd)

APPENDIX II (Cont'd)

Year	Date	Station	Iron	Ortho-Phosphate	Total Phosphate	Nitrite Nitrogen	Nitrate Nitrogen	Silica	Sulphate	Manganese	Copper	Fluoride	Fluorine	Chloride	Chlorine
1968	Aug. 13	4	.18	0	---	0	↓	1.6	75	0.3	.12	---	.41	5.0	.01
		13	.12	0	---	0		2.0	40	.25	.10	---	.50	4.5	.01
	" 21	4	.12	1.50	---	0		1.4	11	0.2	.12	---	.47	5.0	.02
		13	.10	1.00	---	0		2.8	7	2.00	.08	---	.53	5.0	.01
	" 27	4	.13	.20	---	.01	a	2.4	16	0.2	.13	---	.35	5.0	.01
		13	.22	0	---	.01	d	2.8	20	2.50	.09	---	.34	5.0	.01
	Sept. 4	4	.13	.40	---	.01		2.5	34	0.8	.20	---	---	7.5	.02
		13	.18	.40	---	.01	i	3.3	34	.80	.60	---	---	7.5	.02
	" 27	4	.08	0	---	0	n	3.0	28	---	---	---	---	---	---
		13	.08	0	---	0	f	2.5	14	---	---	---	---	---	---
	Oct. 12	4	.10	.20	---	0	i	3.2	19	---	---	---	---	---	---
		13	.06	---	---	0	n	3.5	21	---	---	---	---	---	---
	" 29	4	.03	---	---	0	i	2.3	13	---	---	---	---	---	---
		13	.02	---	---	0	t u	2.6	22	---	---	---	---	---	---
	Nov. 11	4	.10	.17	---	0	m	3.1	9	---	---	---	---	---	---
		13	.10	.10	---	0		3.3	26	---	---	---	---	---	---
	" 22	4	.03	---	---	0		---	13	---	---	.35	---	---	---
		13	---	---	---	---	↓	---	---	---	---	---	---	---	---

(Cont'd)

APPENDIX II (Cont'd)

Year	Date	Station	Iron	Ortho-Phosphate	Total Phosphate	Nitrite Nitrogen	Nitrate Nitrogen	Silica	Sulphate	Manganese	Copper	Fluoride	Fluorine	Chloride	Chlorine
1968	Dec. 6	4	.12	.08	---	↓	↓	3.3	40	---	---	---	---	---	---
		13	.10	.15	---			3.2	46	---	---	---	---	---	---
	" 19	4	.12	.12	---			3.8	20	---	---	.13	---	7.5	0.20
		13	.10	.10	---			3.8	69	---	---	.17	---	7.5	0.2
1969	Jan. 17	4	---	---	---	a d	a d	---	---	---	---	---	---	---	---
		13	.08	---	.05			---	41	---	---	---	---	---	---
	Feb. 5	4	.17	---	0.11	i	i	---	---	---	---	---	---	---	---
		13	.13	---	.15	n	n	---	34	---	---	---	---	---	---
	" 19	4	.10	---	0.04	f	f	---	43	---	---	---	---	---	---
		13	.08	---	.05	i	i	---	52	---	---	---	---	---	---
	Mar. 3	4	.09	---	.06	n i	n i	5.0	23	---	---	.22	---	---	---
		13	.08	---	.09	t	t	5.0	28	---	---	.22	---	---	---
	" 26	4	.10	---	0.02	u	u	6.2	43	---	---	.21	---	---	---
		13	.12	---	.05	m	m	5.8	38	---	---	.19	---	---	---
	Apr. 9	4	.17	.22	.10			5.2	25	---	---	.19	---	---	---
		13	.06	.20	.02			4.6	13	---	---	.08	---	---	---
	" 28	4	.19	---	.08	↓	↓	4.2	29	---	---	.22	---	---	---
		13	.19	---	.08			6.0	29	---	---	.22	---	---	---

APPENDIX II (Cont'd)

Year	Date	Station	Iron	Ortho-Phosphate	Total Phosphate	Nitrite Nitrogen	Nitrate Nitrogen	Silica	Sulphate	Manganese	Copper	Fluoride	Fluorine	Chloride	Chlorine
1969	May 6	4	.21	---	.04	↓ ad infinitum	↓ ad infinitum	2.9	17	0.3	.10	.28	.18	2.5	.01
		13	.13	---	.03			3.6	10	.20	.05	.22	.10	2.5	0.2
	" 13	4	.06	.40	.08			2.8	30	0	---		.30	2.5	---
		13	.07	---	.18			4.0	31	0	---	---	.40	2.5	---
	" 20	4	---	.02	---			3.0	15	0	---		.30	---	.03
		13	---	.02	---			3.5	15	0	---	---	.30	---	0.2
	" 28	4	---	---	---			2.6	12	0	---	---	---	---	---
		13	---	---	---			2.2	12	0	---	---	---	---	---

APPENDIX III

Some Chemical and Physical Characteristics of

Station 4 (warm) and Station 13 (cool)

1968-1969

APPENDIX III

Year	Date	Station	pH	Free CO_2	Bicarbonate Alkalinity	Total Alkalinity	Ca Hardness	Total Hardness	Total Solids	Loss on Ignition
1968	May 15	4	8.6	---	145	175	75	130	328	128
		13	---	---	---	---	---	---	---	---
	" 22	4	8.9	---	155	195	75	120	298	110
		13	8.2	---	155	195	75	125	316	116
	" 30	4	8.8	0.8	160	180	70	132	314	116
		13	---	---	180	200	71	129	324	114
	June 11	4	8.8	0.3	180	200	65	120	480	96
		13	---	---	173	193	71	120	830	94
	" 18	4	8.6	0.6	135	185	80	125	294	108
		13	---	---	145	195	80	140	208	62
	" 26	4	---	---	165	205	80	112	240	84
		13	8.6	0.7	140	180	75	109	262	94
	July 3	4	8.8	0.5	160	200	68	140	282	94
		13	8.6	0.7	130	190	80	110	278	96
	" 9	4	8.7	0.6	110	180	60	135	220	66
		13	8.7	0.7	168	200	75	135	246	88
	" 16	4	8.7	0.3	130	190	80	130	302	116
		13	8.6	0.7	140	200	70	120	286	112
	" 23	4	8.1	---	150	200	70	130	314	130
		13	8.6	0.8	150	200	80	190	324	148
	" 31	4	8.6	0.6	130	190	70	125	302	104
		13	8.7	0.5	120	180	80	150	678	120

(Cont'd)

APPENDIX III (Cont'd)

Year	Date	Station	pH	Free CO_2	Bicarbonate Alkalinity	Total Alkalinity	Ca Hardness	Total Hardness	Total Solids	Loss on Ignition
1968	Aug. 6	4	8.5	0.8	145	185	65	120	694	384
		13	8.2	1.3	150	190	70	130	1812	200
	" 13	4	8.6	0.8	160	210	65	150	282	112
		13	8.6	0.7	130	180	70	150	296	86
	" 21	4	8.4	1.0	140	190	70	120	240	90
		13	8.6	0.9	160	210	85	130	272	128
	" 27	4	8.6	0.6	120	180	70	125	260	86
		13	8.8	0.5	140	200	95	140	286	94
	Sept. 4	4	8.7	0.6	140	200	65	130	292	88
		13	8.7	0.7	140	200	65	135	292	88
	" 27	4	8.7	0.6	150	200	60	120	270	70
		13	8.7	0.7	140	200	60	120	302	136
	Oct. 12	4	8.7	0.8	150	200	60	130	190	---
		13	8.7	0.7	130	190	64	130	310	122
	" 30	4	8.5	1.0	140	200	---	---	300	128
		13	8.5	---	---	---	---	---	320	140
	Nov. 11	4	8.5	1.0	140	190	60	130	328	150
		13	8.6	---	---	195	65	130	324	122
	" 22	4	---	---	---	---	---	---	330	110
		13	---	---	---	---	---	---	---	---
	Dec. 6	4	8.5	0.8	125	185	65	115	316	84
		13	8.6	1.1	150	210	75	120	342	112
	" 19	4	8.4	1.6	155	205	70	125	268	80
		13	8.6	1.2	165	205	75	125	342	80

(Cont'd)

APPENDIX III (Cont'd)

Year	Date	Station	pH	Free CO_2	Bicarbonate Alkalinity	Total Alkalinity	Ca Hardness	Total Hardness	Total Solids	Loss on Ignition
1969	Jan. 1	4	---	---	---	---	---	---	---	---
		13	---	---	---	---	---	---	342	108
	Feb. 5	4	---	---	---	---	---	---	368	136
		13	---	---	---	---	---	---	328	122
	" 19	4	---	---	---	---	---	---	356	104
		13	---	---	---	---	---	---	344	102
	Mar. 8	4	---	---	---	---	---	---	264	52
		13	---	---	---	---	---	---	306	94
	" 26	4	8.3	---	---	---	---	---	370	94
		13	8.3	---	---	---	---	---	310	90
	Apr. 9	4	---	---	---	---	---	---	330	126
		13	---	---	---	---	---	---	264	112
	" 28	4	---	---	---	---	---	---	316	118
		13	---	---	---	---	---	---	316	118
	May 6	4	8.6	1.0	160	180	55	115	314	126
		13	9.1	0.3	160	180	55	110	278	102
	" 12	4	8.8	0.5	180	200	70	110	300	128
		13	8.7	0.8	160	180	60	120	314	134
	" 20	4	8.7	---	185	205	60	110	---	---
		13	8.7	---	220	240	60	120	---	---
	" 27	4	8.6	---	150	170	60	110	---	---
		13	8.6	---	160	180	60	110	---	---

APPENDIX IV Comparison of some chemical characteristics of ice and sub-ice lake water at station 13, winter 1969. (All readings in p.p.m., except temperature in °C.)

Date	Jan. 17		Feb. 5		Feb. 17		M r. 8		Mar. 26		Apr. 9	
	H_2O	ICE	H_2O	ICE	H_2O	ICE	H_2O	ICE	H_2O	ICE	H_2O	ICE
Total Alkalinity	228	20	209	1	217	15	223	16	215	51	172	16
Chlorides	2.0	2.0	2.0	2.0	2.0	0	2.0	2.0	2.0	2.0	2.0	4.0
Fluoride	---	---	---	---	---	---	0.22	0.02	-.19	0	0.08	0.02
Total Hardness	142	5	139	30	136	11	139	14	135	40	106	12
Loss on Ignition	108	32	122	58	102	34	94	34	90	60	112	36
Iron	0.08	0.10	0.13	0.13	0.08	0.03	0.08	0.02	0.12	1.18	0.06	0.13
Nitrite Nitrogen	0	0	0	0	0	0	0	0	0	0	0	0
Nitrate Nitrogen	0	0	0	0	0	0	0	0	0	0	0	0
Ortho-Phosphate	0.02	0.01	0.09	0.04	0.05	0	0	0.03	0.01	0.05	0.01	0.03
Total Phosphate	0.05	0.14	0.13	0.06	0.05	0	0.09	0.04	0.05	0.09	0.02	0.04
Silica	3.2	0	2.2	0	1.5	0.40	2.2	0.06	2.2	0.48	0.08	0.06
Sulphate	41	4	34	2	52	17	28	40	38	19	13	2
Total Solids	342	60	328	82	344	70	306	106	310	126	264	56
Temperature	0.1		0.3		0.1		0.1		0.1		0.1	

APPENDIX V Ccmparison of ratios of some chemical characteristics of ice and sub-ice lake water at station 13, winter 1969. (Ratio water : ice = x : 1)

Date	Jan. 17	Feb. 5	Feb. 19	Mar. 8	Mar. 26	Apr. 9
Total Alkalinity	11.4	209.0	14.5	13.9	4.2	10.8
Chlorides	1.0	1.0	---	1.0	1.0	0.5
Fluoride	---	---	---	11.0	---	4.0
Total Hardness	28.4	4.7	12.4	9.9	3.4	8.8
Loss on Ignition	3.4	2.1	3.0	2.8	1.5	3.1
Iron	0.8	1.0	2.7	4.0	0.1	0.5
Ortho-Phosphate	2.00	2.25	---	---	0.20	0.33
Total Phosphate	0.36	2.17	---	2.25	0.56	0.50
Silica	---	---	3.75	36.67	4.58	1.33
Sulphate	10.25	17.00	3.06	0.70	2.00	6.50
Total Solids	5.7	4.0	4.9	2.9	2.5	4.7

APPENDIX VI

Some Chemical and Physical Characteristics of the Outlet Canal (O.C.), Inlet Canal (I.C.), and Building Products (B.P.) Effluent. (Readings in p.p.m., except Specific Conductance in Micromhos/cm.^{2}, and Turbidity in J.T.U.).

APPENDIX VI 1968 1969

Date	Nov. 22		Jan. 17		Feb. 5	Feb. 19		Mar. 3	June 6			June 17			June 24	
Location	O.C.	B.P.	O.C.	I.C.	O.C.	O.C.	B.P.	B.P.	O.C.	I.C.	B.P.	O.C.	I.C.	B.P.	O.C.	I.C.
Alkalinity	196	204	220	223	225	219	228	247	210	210	220	230	220	250	220	210
Chloride	2.00	2.00	2.00	2.00	2.00	2.00	2.00	0	2.50	5.00	7.50	10.00	2.50	10.00	7.50	5.00
Chlorine	---	---	---	---	---	---	---	---	---	0.01	0.06	0.01	0.02	---	0.03	0.03
Chromate	---	---	---	---	---	---	---	---	---	0.06	0.05	0.10	0.14	0.24	0.18	0.20
Copper	---	---	---	---	---	---	---	---	---	0.10	0	0.20	0.20	---	0.30	0.40
Fluoride	0.32	0.28	---	---	---	---	---	1.03	0.50	-	-	0	→	ad infinitum		→
Calcium Hardness	---	---	---	---	---	---	---	---	---	55	85	80	70	65	70	65
Total Hardness	140	141	143	144	143	144	143	179	110	120	105	110	110	125	120	120
Loss on Ignition	114	102	122	90	126	100	176	378	---							
Iron	0.06	0.10	0.50	0.06	0.10	0.32	0.42	1.90	0	0.05	0	0	0.05	0	0	0
Nitrite Nitrogen	0	0	0	0	0	0	0	0	---	0.01	0	0.005	0	0	0.004	0.005
Ortho-Phosphate	---	---	0.15	---	0.05	0.02	0.13	0.19	0.01	0	0	0.20	0.10	0.20	0	0.10
Total Phosphate	---	---	0.22	0.02	0.12	0.06	0.14	0.69	---							
Silica	---	---	3.30	1.80	2.20	2.00	2.80	2.00	0.03	2.04	1.40	1.60	2.70	1.25	1.90	1.70
Total Solids	262	304	314	324	364	350	428	1062	---							
Sulphate	4	36	18	45	46	59	44	347	22	38	22	10	17	16	10	10
Turbidity	---	---	---	---	---	---	---	---	---	5	45	5	0	135	5	0
Specific Cond.	---	---	---	---	---	---	---	---	---	440	---	440	380	480	520	450
pH							7.22									
Arsenic							0	0.025								

APPENDIX VI (Cont'd)

Date	July 2		July 8		July 15		July 22		July 30		Aug. 15		Aug. 26		
Location	O.C.	I.C.	O.C.	I.C.	O.C.	I.C.	O.C.	I.C.	O.C.	I.C.	O.C.	I.C.	O.C.	I.C.	B.P.
Alkalinity	215	210	225	200	210	203	196	195	200	195	190	240	200	220	220
Chloride	7.50	5.00	8.75	7.50	10.00	3.75	5.00	8.00	7.00	7.50	10.00	7.50	10.00	10.00	10.00
Chlorine	0.03	0.018	0.03	0.03	0.01	0.01	0.01	0.018	0.021	0.03	0.023	0.02	0.025	0.015	0.05
Chromate	0.16	0.16	0.17	0.16	0.14	0.18	0.13	0.12	0.10	0.19	0.08	0.07	0.06	0.18	0.07
Copper	0.25	0.38	0.35	0.32	0.22	0.23	0.18	0.18	0.20	0.24	0.20	0.25	0.20	0.26	0.01
Fluoride															
Calcium Hardness	60	75	75	70	67	70	55	70	60	65	60	63	55	63	85
Total Hardness	125	120	140	130	165	112	110	113	110	105	110	120	110	140	110
Loss on Ignition															
Iron	0	0	0.33	0.10	0.10	0	0	0.01	0.30	>0	0.05	0	0	0.01	0
Nitrite Nitrogen	0	0.005	0.002	0	0.005	0.005	0	0	0.003	0	0.005	0	0.003	0	0
Ortho-Phosphate	0	0.10	0	0.10	0.03	0	0.10	0.10	0.05	0.05	0.20	0	0.10	0.05	0
Total Phosphate															
Silica	1.80	1.80	2.60	2.10	2.70	2.30	2.30	0.85	2.70	2.40	2.80	2.50	2.80	2.30	1.50
Total Solids															
Sulphate	13	11	15	22	11	22	18	22	18	22	18	17	18	20	23
Turbidity	9	0	0	12	5	0	12	2	2	10	0	15	2	10	40
Specific Cond.	540	500	470	500	480	470	465	455	480	460					
pH															
Arsenic															

APPENDIX VII

Water Chemistry 1970 (p.p.m.)

	June 19		July 22	
	Outlet Canal	Sundance	Outlet Canal	Sundance
Alkalinity	170	180	140	180
Chloride	0.05	0.15	3.0	5.0
Chlorine	0.02	0.01	---	---
Copper	0.2	0.1	0.15	0.15
Calcium Hardness	90	---	70	60
Total Hardness	135	90	135	120
Iron	0	0	0.025	0.025
Ortho-Phosphate	---	0.1	0.9	0.8
Silica	0.1	0.01	1.7	2.0
Sulphate	37	22	25	18
Turbidity	8	5	10	5

APPENDIX VIII

Some Chemical and Physical Characteristics of Bottom Sediments

at Lake Wabamun, stations 4 and 13, 1968-1969

(Conductivity in millimhos/cm 1969; * = lbs./acre; H = High; M = Medium; L = Low)

APPENDIX VIII

Month	Station	Conductivity	Iron (p.p.m.)	Free Lime	Nitrogen*	Organic Matter	pH	Phosphorus*	Potassium*	Sodium	Sulphates (p.p.m.)	Texture
1968 June	4	1.5	---	M+	6.0	L	7.9	22	398	H	0	4.0
	13	2.2	---	M	20.0	L	7.8	67	485	H	M	3.0
July	4	1.8	---	M	12.0	L-	8.0	8	422	H+	L	3.0
	13	2.0	---	L	14.0	L-	7.9	102	800	H+	L	3.0
Aug.	4	2.5	---	M	0	L	7.6	33	449	M	L-	4.0
	13	3.8	---	L-	2.0	L+	7.5	78	481	H+	L-	2.0
Sept.	4	2.4	---	L	1.0	L-	8.0	41	336	H+	H-	2.0
	13	3.9	---	H	5.0	L	7.8	266	638	H+	H	2.0
Oct.	4	1.3	---	L+	4.0	L-	7.8	39	333	M	L-	2.0
	13	1.9	---	L-	0	L	7.6	66	371	H+	L-	2.0
Nov.	4	1.7	1.0	M+	10.0	L	7.5	38	788	H+	L-	4.0
	13	2.9	1.0	L-	9.0	L	7.9	53	1000+	H+	L-	4.0
Dec.	4	1.9	1.0	M	2.0	L	7.9	61	910	H+	L-	4.0
	13	2.5	1.0	L	12.0	L+	7.1	137	722	H+	L	4.0
1969 Feb.	4	1.7	1.0	M	4.0	L	7.7	29	499	H+	L-	4.0
	13	3.0	1.0	L-	17.0	L+	7.1	173	671	H+	L-	4.0
Mar.	4	1.7	1.0	M	1.0	L	7.5	62	671	H+	L-	4.0
	13	2.2	1.0	L	8.0	L	7.2	168	646	H+	L	3.0
May	4	1.3	1.0	L+	1.0	L	7.5	69	512	H+	L-	4.0
	13	1.7	4.0	L-	11.0	L	6.9	105	536	H+	L-	3.0

APPENDIX IX

Preliminary List of Organisms Found in Lake Wabamun

Protista

Acanthocystis sp.
Acineta lacustris
Actinobolina sp.
Actinophrys sol
Actinosphaerium sp.
Amoeba gorgonia
A. radiosa
Anisonema truncatum
Anisonema sp.
Astylozoon sp.
Bodo sp.
Carchesium sp.
Ceratium hirundinella
Chilodonella sp.
Chlamydomonas sp.
Chrysamoeba sp.
Ciliophrys sp.
Coleps octospinus
Coleps spp.
Cryptomonas sp.
Cyclidium sp.
Didinium sp.
Dileptus sp.
Entosihphon obliquem
Euglena variabilis
Euglena spp.
Euplotes sp.
Exuviaella sp.
Flabellula sp.
Glenodinium cinctum
Gonyaulax sp.
Gymnodinium sp.
Lagenocera sp.
Naegleria sp.
Nassula sp.
Nephroselmis sp.
Notosolenus sp.
Ophrydium sp.
Oxytricha bifaria
O. fallax ?
Paramecium sp.
Pelatomonas asymmetrica
Peranema sp.
Peridinium sp.
Petalomonas sp.
Phacotus sp.
Phacus longicauda
Phacus sp.
Pleuromonas sp.
Psilotricha sp.
Pteromonas sp.
Scyphidia sp.
Stentor sp.
Stylonychia sp.
Symnodinium sp.
Trachelomonas sp.

(Cont'd)

APPENDIX IX (Cont'd)

Trichamoeba limax

Tropidoscyphus sp.

Uroleptus sp.

Vaginicola sp.

Valkampfia limax

Valkampfia sp.

Vorticella neustonii

Vorticella sp.

\+ Unidentified spp.

INVERTEBRATA

Porifera

Spongilla sp.

Coelenterata

Chlorohydra hadleyi

Hydra canadensis

H. carnea

Turbellaria

Cura foremanii

Dugesia tigrina

Gyratrix hermaphrodius

Nematoda

Unidentified spp.

Gordiida

Unidentified spp.

Gastrotricha

Chaetonotus sp.

Rotifera

Ascomorpha ecaudis

A. minima ?

A. saltans

Ascomorphella (=Hertwigia) volvocicola

Asplanchna priodonta

Brachionus patulus

Cephalodella sp.

Chromogaster ovalis

Collotheca pelagica

Colurella sp.

Conochiloides exiguus ?

Conochilus hippocrepis

C. unicornis

Dipleuchlanis sp.

Encentrum sp.

Eothinia sp.

Epiphanes sp.

Euchlanis sp.

Filinia longiseta

Gastropus hyptopus

G. stylifer

Kellicottia longispina

Keratella cochlearis

K. earlinae

K. hiemalis

Lecane luna

Mikrocodides chlaena

Monostyla sp.

Mytilina sp.

Notholca acuminata

N. foliacea

Ploesoma lenticulare

Polyarthra euryptera

P. rematra

P. vulgaris

Scaridium longicaudum

Sinantherina sp.

(Cont'd)

APPENDIX IX (Cont'd)

Squatinella sp.
Synchaeta pectinata
Testudinella sp.
Trichocerca dixon-nuttalli
T. longiseta
T. multicrinis
T. porcellus
Trichotria pocillum
T. tetractis
Trochosphaera aequatorialis

Bryozoa
Cristatella mucedo
Fredricella sultana

Tardigrada
Macrobiotus sp.

Oligochaeta
Aelosoma sp.
Cambaranicola macrodonta
Tubifex sp.

Hirudinea
Unidentified spp.

Cladocera
Bosmina longirostris
Ceriodaphnia reticulata
Daphnia galeata mendotae
D. retrocurva
D. rosea
Diaphanosoma leuchtenbergianum
Eurycercus lamellatus
Leptodora kindtii
Sida crystallina
Simocephalus serrulatus
S. vetulus

Copepoda
Cyclops bicuspidatus thomasi
C. vernalis
Diaptomus oregonensis
Eucyclops speratus

Ostracoda
Unidentified spp.

Malacostraca
Gammarus lacustris
Hyalella azteca

Insecta

Ephemeroptera
Caenis simulans
Unidentified spp.

Hemiptera
Unidentified spp.

Trichoptera
Unidentified spp.

Diptera
Chaoborus spp.

Chironomidae
Ablabesmyia monilis
Calopsectra confusa
Chironomus sp.
Diamesa sp.

(Cont'd)

APPENDIX IX (Cont'd)

Paralauterborniella sp.
Polypedilum sp.
Procladius sp.
Tantarsus sp.
Unidentified spp.

Acari
Unidentified spp.

Mollusca
Anodonta sp.
Heliosoma anceps
Lymnaea stagnalis
Menetus dilatus
Physa heterostropha
Pisidium sp.
Sphaerium sp.

VERTEBRATA

Pisces
Catastomus commersonii
Coregonus clupeaformis
Culaea inconstans
Esox lucius
Etheostoma exile
Lota lota
Notropis hudsonius
Perca flavescens

Aves
Aechmophorus occidentalis
Agelaius phoeniceus
Anas platyrhynchos
Bucephala sp.
Chilidonias niger
Gavia immer
Pandion haliaetus
Pelecanus erythrorhyncos
Podiceps caspicus
Sterna hirundo
Xanthocephalus xanthocephalus

Mammalia
Ondatra zibethicus spatulatus

Appendix X. Comparison of bottom fauna organisms at stations 4 and 13, 1968-1969.

		Station 4 (warm)						Station 13 (cold)					
Year	Date	Chironomidae	Mollusca	Oligochaeta	Acari	Chaoborus	Other	Chironomidae	Mollusca	Oligochaeta	Acari	Chaoborus	Other
1968	June 26	++++	-	+	-	-	-	++	-	-	-	+++	-
	July 4	++++	-	-	-	-	-	-	-	-	-	-	-
	" 9	++++	R	-	-	-	-	-	-	-	-	-	++++
	" 16	++++	-	-	-	-	-	++++	-	-	-	-	-
	" 23	-	++++	-	-	-	-	-	-	-	-	-	-
	Aug. 6	+++	-	+	+	-	+	++++	-	-	-	-	-
	" 14	-	++++	-	-	-	-	-	-	-	-	-	-
	" 21	-	++++	-	-	-	-	-	-	++++	-	-	-
	" 28	++++	-	-	-	-	-	-	++++	R	-	-	-
	Sept. 4	-	++++	-	-	-	-	-	-	-	-	-	-
	" 27	+++	+	+	+	-	-	R	-	R	-	++++	-
	Oct. 12	-	++++	-	-	-	-		No Sample				
	Nov. 11	-	++++	-	-	-	-	++++	-	-	-	-	-
	" 22	-	++++	-	-	-	-		No Sample				
1969	Jan. 15	+++	+	-	-	-	+		No Sample				
	Feb. 6	+++	R	-	++	-	R	++++	-	-	-	-	-
	" 19	++	R	-	+++	-	R	-	-	-	-	-	-
	Mar. 8	++	R	-	++	-	R	++++	-	-	-	-	-

(Cont'd)

Appendix X (Cont'd)

Year	Date	Station 4 (warm)						Station 13 (cold)					
		Chironomidae	Mollusca	Oligochaeta	Acari	Chaoborus	Other	Chironomidae	Mollusca	Oligochaeta	Acari	Chaoborus	Other
1969	Mar. 26	+++	+	-	+	-	R	++	+++	-	+	-	-
	Apr. 9	++	++	-	+	-	R	++++	-	+	-	-	-
	" 28	++++	R	-	R	R	+	+++	-	+++	-	-	-
	May 6	++	+	R	+	-	+	-	+++	-	-	++	-
	" 13	+	++		R	-	++	-	+	-	-	++++	-
	" 20	++	+++	R	-	-	R	+	+	-	-	+++	-
	June 2	++	+++	R	-	-	R	-	+++	-	-	+++	-
	" 10	++	++	+	-	-	+	+++	++	-	-	-	-
	" 24	++	++	++	-	-	+	++++	-	-	-	-	-
	July 2	+	+++	+	-	-	-	++++	-	-	-	-	-
	" 8	+++	+	R	R	-	+	-	+++	-	-	+++	-
	" 15	-	-	-	-	-	-	++++	-	-	-	-	-
	" 30	+++	+	R	R	-	+	+++	.+++	-	-	-	-
	Aug. 7	+	+++	R	+	-	R	-	-	-	-	-	-
	" 14	+++	+	-	+	R	-	-	-	-	-	-	-
	" 28	+++	+	-	+	-	R	-	-	-	-	-	-

Key: ++++ > 75% of species composition
+++ = 50 - 74% of species composition
++ = 25 - 49% of species composition
+ = 10 - 24% of species composition
R < 10%
- = absent